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ABSTRACT

This volume presents historical sketches of events and scientists. Produced for use by teachers using the MINNEMAST curriculum materials, the material is intended to exhibit the roles of processes in science throughout history. The seven stories included concern Anaxagoras, Achimedes, Napier, the development of the telescope and microscope, Louis Agassiz, Otheniel Marsh and natural history, and ancient systems of numeration. A table provides the teacher with information concerning the skills and concepts illustrated by each story. The processes listed are: calculation, classification, description, experimentation, hypothesis making, measurement, model building, and observation. (SD)

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ADVENTURES IN SCIENCE AND MATH

by

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FOREWORD

These true stories of science adventures and adventurous scientists illustrate familiar aspects and processes of science; they also include some interesting episodes in the history of mathematics. Particular stories have been selected not merely for their quality as stories but also because they bear on major topics: the birth of the scientific method, varieties of research approaches, the role of instruments in the development of science, mathematical notation, and simple calculating devices. Moreover, in these pages the reader will discover examples of observation, description, measurement, classification, experimentation, deduction, and hypothesis making – recurring themes in the MINNEMAST curriculum.

The use of this material is best left to the discretion of the teacher. Much will depend on the abilities and interests of the individual classes to be taught; as we all know, classes differ widely in these respects. Most third-graders will not be able to read these stories by themselves. Thus, it will be most practical for the teacher to read to the class as a whole, usually dividing each story into parts and reading a section at a time. On occasion, a story might be combined with a demonstration or an experiment as, for example, in the case of Anaxagoras or Archimedes. In any event, the imaginative and experienced teacher who gives thought to the matter should have no difficulty in deciding when and how to introduce a particular item.

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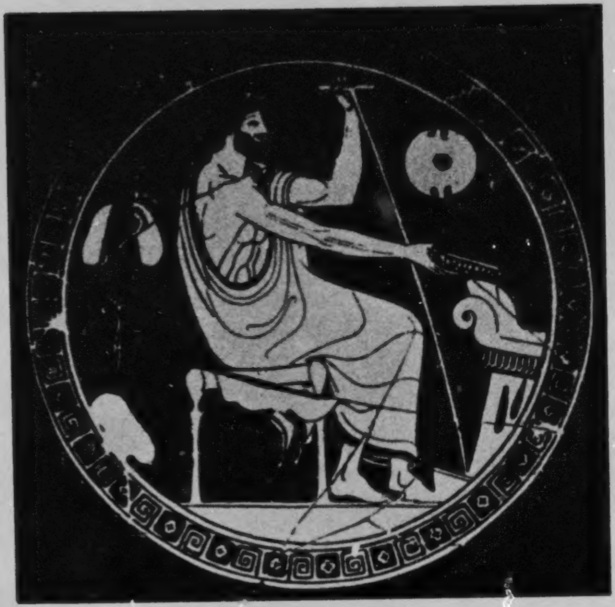
MR. ANAXAGORAS



MR. ANAXAGORAS

Do you ask questions? Many questions? Of course you do! Everyone does, and everyone always has as long as there have been boys and girls — and grown-ups, too. Think of all the things you'd never know unless you asked questions!

Now, you know that there are all kinds of questions. Silly questions. IMPORTANT QUESTIONS. And just plain nuisance questions. But there are certain kinds of questions that children and grown-ups have been asking ever since the world began. Questions like —

How did the world begin? What is the world made of? Where does the sun go at night? Why is there a rainbow? Why does it thunder? And many others of the same sort.

Long, long ago people didn't really know the answers to these questions – some of the old ones can't be answered even now, but when a child asked his parents, or when a grown-up asked some big, important person, whoever asked the question expected an answer, and he usually got one – good, bad, or in between. Some answers, for one reason or another, seemed like good ones. At least, they satisfied the curiosity of the person who had asked the question. In fact, these good answers came to be accepted as true ones. So when a child asked his father a question about the rainbow, for example, his father would repeat the answer he had heard from his own father or mother. A common or standard answer of this kind, which is handed down from parent to child again and again, is called a myth. And in the old days, and in some places in the world right now, there were – and still are – different sets of these myths. An American Indian tribe might have one set. A tribe in Africa might have another. Or the curiosity of boys and girls and grown-ups in China or India might be satisfied by others.

We know today what some of these myths were like. And, frankly, very often they don't make much sense to us. But in the old days people were so busy tending their sheep, or hoeing their corn, or making arrowheads that they didn't have much time to hunt for better answers. Perhaps the children weren't always pleased with the answers they got, but as for most grown-ups – well, they had other things to worry about. Their minds were so crowded with everyday problems that there wasn't any room for thoughts about the rainbow or the Man in the Moon.

Let's take the Babylonians, for example – they were people who lived in the Middle East more than three thousand years ago. If a child had a toothache, he wouldn't be told that he had a toothache because he had been eating too much candy, or hadn't been brushing his teeth three times a day, or hadn't seen his dentist twice a year. No, his mother would tell him the myth of the worm, which went something like this:

When the world had been created, or made, by the chief spirit or god, the chief spirit decided what every kind of living creature should eat. Cows were to eat grass and grain; lions were to eat meat, and so on. But the chief spirit had forgotten about the worm. The worm had nothing to eat and got very hungry, so he came to the chief spirit and complained about it. This was a real problem, because all the kinds of food had already been given to the other creatures. So, as a last resort, the chief spirit ordered that the worm should eat people's teeth. And it's plain to see that if there is a worm eating your teeth, you are going to have a toothache.

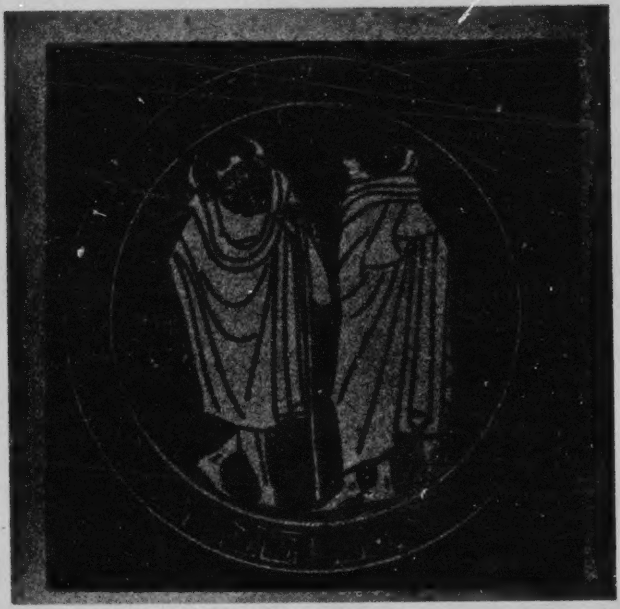
These same Babylonians had another myth. This one was about how the world began, and it was usually recited as a poem. The name of the poem was Enuma Elish, which means "When above." It was called by this name because these were the first two words of the poem. The first line went something like this:

"When above the heavens had no name."

This means that the sky had not been made yet – there wasn't any sky, and the poem goes on to say that there wasn't any earth, either. There was nothing but water. In the water lived a cross lady dragon who had many children, all of them very naughty dragons who caused a lot of trouble for the chief spirit and all his relatives. At last, the dragons made so much trouble that the chief spirit decided to get rid of them. There was a big war in which he destroyed the cross dragon and her children, and then he cut the big dragon in two: one half of her skin rested or floated on the water and became the earth, while the other half was raised up to form

the sky. The chief spirit had made so many holes in the dragon's skin with his spear that you could see the sun and stars through them, and people said that rain was caused by water coming through these holes, too. After this, the chief spirit made all the plants and animals and people, and he organized the whole world into the way it is now. And this, said the Babylonians, was how the world began.

Now, this story about how the world began was used by the Babylonians for years and years. The longer it was used, the more true it seemed, just because so many people had used it for so long. After all, they felt that if it was good enough for grandpa and great-grandpa, and great, great-grandpa, it was plenty good enough for anybody else.



After a while, the story began to be borrowed by the neighbors of the Babylonians and then by their neighbors' neighbors until the myth was known to people who lived hundreds of miles away. At last, it came to the Greeks. And when it did, a very strange thing happened!

But first, let's talk a little bit about the Greeks.

Up to this time – that is, up to about twenty-five hundred years ago – the Greeks had not been civilized like the Babylonians or like the Egyptians, the people who built the pyramids. The Greeks had been rather poor. They lived in little villages and raised a little grain and a few sheep and goats. They were mainly farmers and fishermen. They made most of the things they needed at home, and so for a long time they didn't trade or have much to do with other people.

The Babylonians and the Egyptians, on the other hand, had been civilized for years. They lived in big cities. Their farming and manufacturing were done on a big scale, and they traded their cloth and jewelry and many other fine products for the wood and stone and silver and copper and other things that their neighbors had and which were not found in Egypt and Babylonia. The Babylonians and Egyptians had each developed a system of writing. They knew a lot about medicine and mathematics and astronomy. The rich and powerful Egyptians and Babylonians were like the people of the United States or England and France or any civilized country nowadays. They had everything that was new and up-to-date, while the Greeks were like the people of some of the underdeveloped countries of the world today where the people are poor and may not have schools or machines or the fine things that we find so pleasing and convenient.

But the Greeks were ready for civilization. They were beginning to trade with the part of the world that was civilized. And, as they returned home with the cloth and jewelry and perfumes of Egypt and Babylonia which they had bought with their own wine and olive oil, they also brought back ideas from those countries. These ideas were new and strange to the Greeks. Some of them they just accepted and used as best they could – like writing and money and business methods, but other ideas the Greeks changed.

The fact was that all the new and strange things that the Greeks discovered in Egypt and Babylonia made them think about things that they had never thought about before. As they saw that these civilized people lived in a different way than the Greeks did and had many different ideas, the Greeks began to wonder about some of their own myths and other things that they had always believed.

If you were faced with two different stories about how the world began, what would you do? Take a myth from someone else? Keep your own? Or throw both away and try to figure out something better?

Well, the Greeks didn't do any of these things. Very often they would keep a part of one of their own ideas and put it together with a part of one of the Egyptian or Babylo-

nian ideas. And what happened? All at once, they had a new idea which was sometimes better than either of the old ones from which it had come.

It was like taking some pieces from a set of Tinker Toys and putting them together with some pieces from an Erector set. Why would they do this? My guess is that they couldn't bring themselves to throw away everything of their own. But, on the other hand, they had already learned so much from their civilized neighbors that they respected them greatly and felt that there must be some good even in an idea that sounded pretty silly.

Now, there was one of the Greek towns that had more trade and more contacts with the civilized area than most of the other towns at this time. Its name was Miletus, and it was located on the shore of the Aegean Sea in what is now the western part of Turkey. It was also in Miletus that the first Greek scientists lived. These scientists not only picked up ideas from the traders who came back from the Middle East, but some of them actually went to Egypt and other places to get first hand information. Although these early scientists were most interested in mathematics and astronomy, they also made guesses and tried to figure out things about what the world was like and how it began.

And that brings us back to the Babylonian story about the cross dragon and the chief spirit and how the world began. You'll remember that the chief spirit made the world by cutting the dragon in half and using one half for the earth and the other for the sky. You'll remember also that this whole affair floated on the surface of the water – the water that had been there before there was either earth or sky.

Now the Greeks were not likely to take the dragon or the chief spirit very seriously, but water did mean something to them. The Greeks were sailors, and many Greeks lived on islands, so it wasn't hard for them to imagine that the earth was completely surrounded by water and probably floated on it. Furthermore, the Greeks had always thought of water as being alive. Water moved. It came gushing out of springs. It flowed in rivers. There were water currents in the sea. Not only that, but plants needed water to grow. A seed wouldn't grow unless you put water on it, and a plant would die if you didn't water it. So, water must be alive, and it must have the power to give life to other things.

What happened? Well, the first of these Greek scientists who lived at Miletus – his name was Thales – came up with an idea. The earth, he said, was like a cork or bowl floating on top of the water, and the whole thing was covered by a huge bowl turned upside down – this was the sky. The original waters and the two halves of the dragon's skin were still there, you see, but the dragon and the chief spirit had been left out. Thales had kept the idea – or model, as scientists call it – but he had thrown the myth away.

But what about the beginning and nature of things? Thales didn't doubt that the world had had to begin somehow, and he was sure that the people and plants and animals must have come from somewhere.

So what did Thales do? He went back to the Babylonian idea that in the beginning there was nothing but water. And then, he said, since water has life, everything must have come from the water in some way – the earth, air, plants, animals, everything. Again, he left out the chief spirit. He threw the myth away, but he kept the idea.

You can well imagine that not everyone was willing to accept Thales' ideas. The bowl floating on the waters kind of model seemed possible enough, but there was just too much that Thales couldn't explain about how everything could come from water. So, other people began to make suggestions, and one Greek scientist said something like this:

"Water is only one of four common things, or elements, in the world. The others are earth, mist, and fire. Once upon a time these four things lay wrapped around one another like the flavors in an ice cream roll. The earth, which was the heaviest, was in the center. All around that was water, and around the water was mist, and on the outside was fire."

This was something like the two halves of the dragon, one of which rested on the water and was covered on top by air, and outside the other half were fiery bodies like the sun and stars.

To account for the beginning of things, this second scientist said that the fire heated the water into steam and dried out the earth. Then the whole affair got so hot that it blew up. The fire went out into space. The mist stayed in between the fire – which was on the outside – and the earth and water, which remained at the center on the inside.

Thales' idea that everything must have come in the beginning from a single source seemed like a good one, but our second scientist argued that this couldn't have been water, because water, earth, mist, and fire all changed into one another. After all, he said, if you heat water, it turns into steam or mist, and probably if you get it hot enough it will burn. Or, if you let a pan of water sit for a while, it will evaporate. That is, some of the water will become mist, and what you will have left is some dirt in the bottom of the pan. The four elements, said our scientist, must have come from the same thing, but what had produced fire, mist, earth, and water in the first place, he was unable to say.

This was a little weak, you must admit, and so it wasn't long before a third scientist had a bright idea. He decided that the basic element was mist and that it stayed the same or changed into other elements depending on how hot or how cold it was. Cold would make mist into water, and then into earth, he said, while heat would turn mist into fire.

"Why," he said, "you can perform this experiment for yourself. You can change the temperature of the mist. Open your mouth wide and blow on your hand. The mist that comes out of your mouth will be hot. But if you put your lips close together and blow, you will feel a cold stream on your hand."

All this was hard to explain. You could see that something did happen depending on how hard you blew, but you

couldn't easily tell why. Most people were not happy with the mist idea, and so it wasn't long before some one had another.

A fourth scientist pointed out that no one of the people who had talked about the basic elements had really explained how or why they changed into something else. He had noticed that clay put in the potter's oven was changed by heat into pottery. Cooked foods were not like raw ones. Copper ore could be heated until it became copper, something very unlike the substance from which it had been smelted. Fire, then, must be the basic element because its action changed the form of the others.

Now, let me ask you this:

Do these old Greeks sound like scientists to you? What do you think scientists ordinarily do that these people were not doing? Should we call them scientists at all?

Of course, they didn't call themselves scientists. Scientist was a word that hadn't been invented yet. If you had asked Thales what he was, he might not have had an answer for you, but his friend Pythagoras would have said that he was a philosopher, which means a lover of wisdom, or knowledge.

To come back to our question – should we call these people scientists? True, they didn't have computers or laboratories with lots of equipment or test tubes and microscopes, yet having equipment is not the whole story at all. You could have all that equipment yourself and still not be a scientist. No, it's what you do, not what you have, that makes the difference.

Did they observe? Did they count and measure? Did they keep records? Did they analyze their data from these records? Probably not, or at least not very much.

So, what was scientific about these old Greeks? It was mainly in the way that they were thinking about things. They were not satisfied with little stories about how something began or what it was made of. They didn't want to have to explain something by saying that a witch or spirit did this or that. Instead, they looked at nature, at the things in the world that they could see or hear or feel or even taste, and they tried to explain other things in those terms.

Rightly or wrongly, it seemed to them that there were certain facts that they could be sure of. Not only they, but all the rest of the Greeks at that time, took it for granted that there were four elements: fire, mist, water, and earth. Most people believed that water was living stuff, and there were other "facts" that no one questioned. Therefore, the Greek scientists determined to take their facts and fit them together into theories that would explain or account for the beginning of the world, and so on. If some one had a toothache, for example, it would be much better in the long run to try to find out what was causing it and search for a cure rather than saying that it was because of the worm or because some evil spirit was in the tooth.

What the Greeks were trying to do was good, but they couldn't prove that water, earth, mist, or fire were elements, or, as some of the people who came after Thales suspected, mixtures or compounds of even more simple things. Moreover, they usually did not take the next step after putting a theory together. They seldom tested their theories by experiments, and you already know how important experiments are in the work of a scientist.

All this brings us to the second part of our story. It's about still another Greek scientist. This one was born about one hundred years after Thales, and he was one of the first to test his theories by experiments. His name was Anaxagoras.

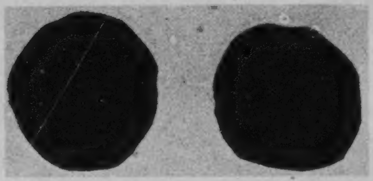
II

Anaxagoras was very famous. People called him "The Mind," or, as we would say, "The Brain!" He was born in a town not far from Miletus, and when he was a young man he went to school in Miletus itself. There, one of his teachers was that third scientist we talked about earlier — the one who did the experiment of blowing on his hand and who said that mist was the basic element. His name, in case you are interested, was Anaximenes.

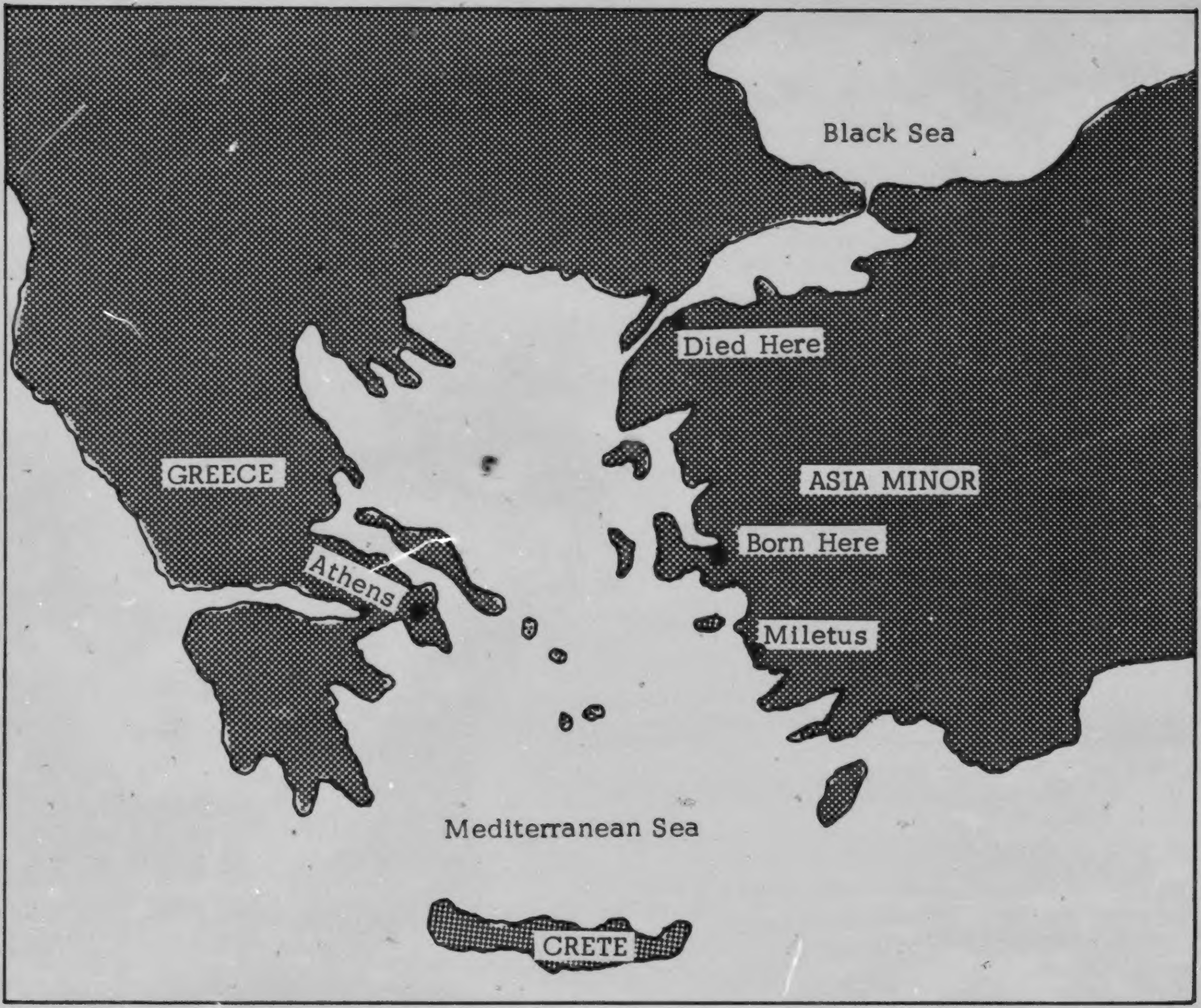
In the time of Anaxagoras, Miletus was not as important as it had been when Thales was alive. Instead, Athens, across the sea on the mainland of Greece, was the place where every ambitious young man wanted to go in order to make his fortune or to become famous. It wasn't surprising,

Miletus Coin

Athenian coins



AREA WHERE ANAXAGORAS LIVED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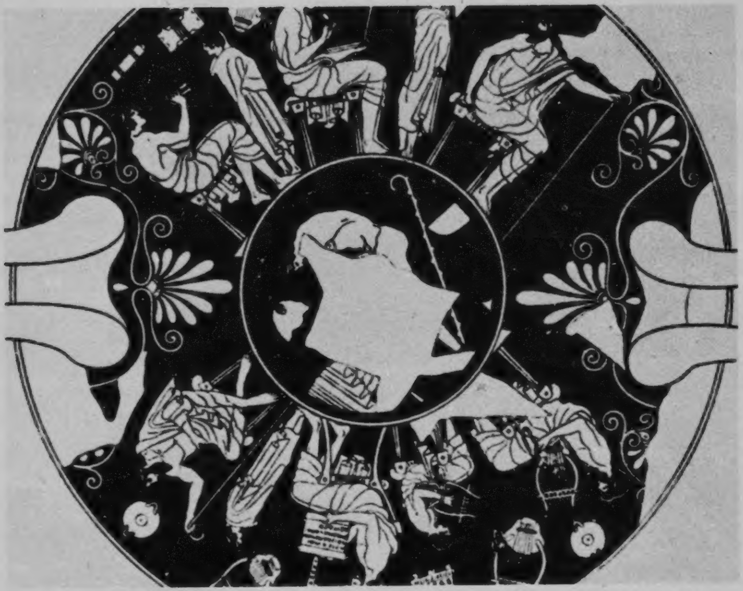


then, that Anaxagoras went to Athens after he finished school in Miletus. In Athens people were interested in science, and Anaxagoras made his living as a teacher. Among his students were several well-known Athenians who also became his good friends. One of these was Pericles, the most important man in Athens at this time – he was what we might call the President of Athens for many years. Another was Euripides, who wrote many plays that are still famous and often performed in our theaters or made into movies.

Anaxagoras was not only interested in mathematics and astronomy, but he also had theories about plants and animals, how the world began, why the sea is salty, and lots of other things. He could explain why eclipses occur. He said, too,

that the moon gets its light from the sun, and that there are mountains and valleys on the moon.

Whenever he could, Anaxagoras tested his theories by experiments. One of his experiments was much admired. It was simple to perform, but its results were very convincing. This experiment might be described as follows:

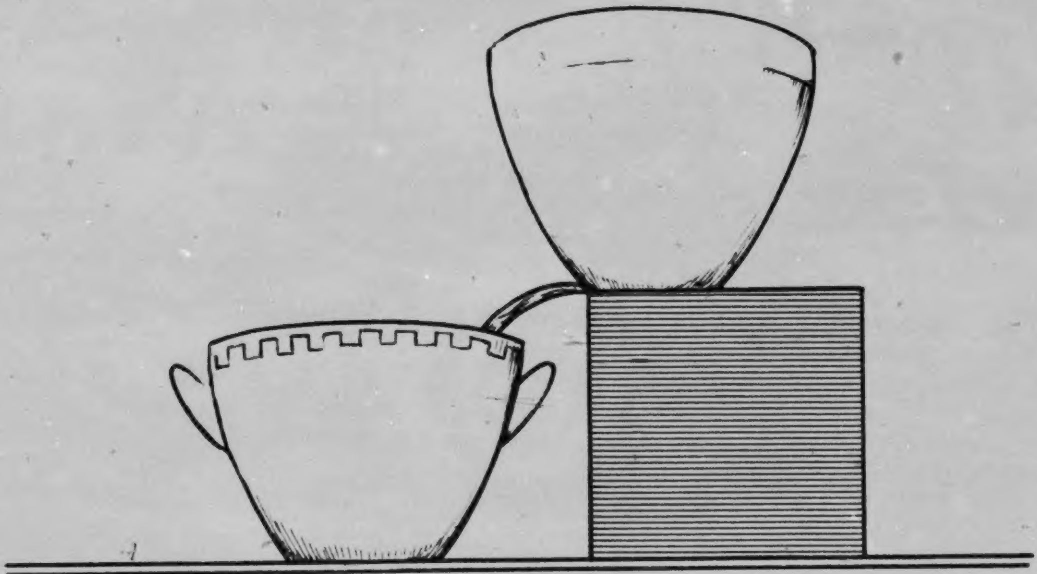
You may have noticed that the early Greek scientists talked about common, everyday things like earth, mist, fire, hot and cold, and the like, but nothing much was said about air. This was because while people could feel wind, they couldn't see air and weren't really sure whether there was any such thing. Anaxagoras, however, found ways of showing that air does exist.

First, he took a wineskin and blew it up like a balloon. By twisting the neck of the wineskin he made it as hard as a football and thus showed that air takes up space and can stand a lot of pressure or weight from the outside.

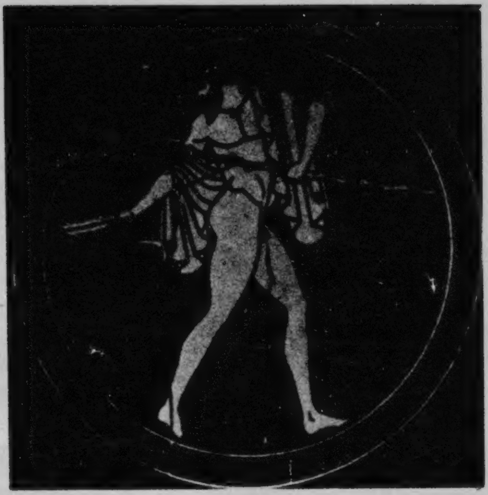
Next, he took a water-clock. What is a water-clock? Well, let me explain –

Perhaps you have seen what used to be called an hour-glass or one of the little egg-timers that they sometimes sell in variety or hardware stores. If you have, you'll remember that these are used for measuring time: a certain amount of sand flows from the top of the glass container through a small hole into the bottom part of the glass. The amount of sand is carefully measured, and the size of the small hole is just right so that in an egg-timer, for example, it takes three minutes for the sand to flow from the top to the bottom of the glass.

Well, the Greeks didn't have such sand-glasses. They had water-clocks, instead. They filled a vessel of a certain size with water and then allowed the water to run out through a small hole in the bottom. One type of water-clock was shaped like an ice cream cone. You poured the water in the big end, and it ran out a little hole in the small end.



Water-clock



Anaxagoras took one of these cone-shaped water-clocks. He filled it with water and then covered the big end tight. When people asked why the water didn't run out of the small end, Anazagoras explained that the pressure or force of the outside air held the water in. Then he turned another cone upside down and put his finger over the hole in the small end. When he tried to submerge the cone in water by putting the large end directly into the water, it simply couldn't be done. This showed that air was taking up space on the inside of the cone. Water could not enter the cone unless Anaxagoras allowed some air to escape by lifting his finger from the small hole. This proved once again that air takes up space, or has volume.

What else do we know about Anaxagoras?

Well, did you ever think how different our lives would be if we didn't have hands equipped with fingers that can hold or make things? Our hands and the ways in which we can use them make us quite different from most animals. Anaxagoras was one of the first people to realize how important our hands are. He put it this way: "Man is the wisest of animals because he has hands." Can you think of a better way to say this?

Another thing that attracted the quick mind of Anaxagoras was the problem of sensation, or how our senses operate. He had a theory that we feel, hear, smell, taste, or see something only when its opposite excites or irritates the sense organ involved – eyes, tongue, nose, ears, or skin. If we touch something that is the same temperature as our bodies, we will not think of it as either hot or cold. We often feel that something is sour after we have been eating something else that is sweet. If we look through a colored glass at an object of the same color, we may not be able to see it very well, or, we can sometimes see light-colored objects in the dark, but not black ones.

Not all the ideas of Anaxagoras were equally good, as I have said. Sometimes he let his imagination run away with him as, for example, when he tried to explain how the world began.

Anaxagoras said that in the beginning there was no heaven or earth and that everything was all mixed up together in a mass. Then this mass began to whirl around. Heaven and earth separated from each other, and the elements began to separate, too. The air was especially active and continued to move about. Hot, fiery air rose upwards because it was light in weight, while the dense, heavy air settled downwards, and

its wet parts formed the sea and its drier parts the land. This happened because everything was whirling around. It seemed to Anaxagoras that the fiery things like the sun and stars had never stopped whirling.

He then went on to say that at first the earth was muddy and soft and bubbled up when the sun shone on it and then cooled off at night. The bubbles finally burst. Out of them came living things. Those which had a great deal of heat in them rose up and became birds. Those which were colder became animals, and those which were wettest became fish. Finally, the earth hardened, bubbles weren't formed any more, and no new creatures were produced after that.

Anaxagoras made other wild guesses. He thought that the earth was flat and that it stayed in place in the heavens because it whirled around like a Frisbee and was thus supported or held up by the air beneath it. He believed that the sun was very large but not nearly so large as the earth. Again, people understood why their wheat and barley and vegetables grew in their gardens and fields because they themselves had planted the seeds for such crops, but they wondered about wild plants which, of course, did not receive the same care. Anaxagoras thought that the seeds of the wild plants were always floating about in the air and that the rain washed these seeds down to earth. In a way, he was right about this, but what do you think he didn't know?

Many people respected Anaxagoras in spite of his wild guesses, and, because he was so famous, all kinds of stories

began to be told about him in the centuries after his death. People said that he could predict what was going to happen – that he predicted the fall of a blazing stone, a meteorite, from the sky, that once he went to a big public gathering wearing a kind of raincoat when everyone else thought it would be a fine day – but it did rain, and Anaxagoras was the only one who didn't get soaked. It was also said that he was a kind of absent-minded professor who didn't care about making money or having nice clothes. It was related that when some one asked Anaxagoras why he had been born, Anaxagoras pointed to the starry heavens and said, "To look at all this!"

On the other hand, there were some people who didn't like Anaxagoras very much. His ideas were different from those they had learned as children, and they found this upsetting. When he said that the sun is a burning stone, they were offended because they had been taught to believe that the sun is a god or spirit. Finally, when Athens was involved in a great war and everyone was frightened, people couldn't think calmly any more, and Anaxagoras was driven out of Athens because his ideas were unlike those of other people and seemed very dangerous. He left his friends, who could not protect him from those who wished to harm him, and went to another town far away from Athens where he was welcome because of his fame, and, after a while, he died there.

There is a nice story about Anaxagoras. When he was very old and did not expect to live much longer, he was asked how he wished people to remember him. Would he like to have a statue in the public square or something of that sort? And what did he say? He replied that he hoped the day of his death would be made a holiday for school children. And so, as we have a holiday on Washington's or Lincoln's birthday, on the anniversary of the death of Anaxagoras, the children of that town forever after did not have to go to school.

III

If we look carefully at the myths, at early Greek science, or at the experiments of Anaxagoras, we can learn something about good and bad answers to questions.

A myth was just an answer or a wild guess. It might satisfy the person who asked the question, but that was the end of it. It didn't lead to anything else.

The Greeks went a step beyond myth-making. You might say that they were forced to do this when they found that their myths and the myths of people whom they respected did not agree. What could the Greeks do? What did they do? They tried to find something sensible and reasonable or believable in the myth that seemed to agree with what anyone could observe in nature itself.

Unlike people before them, the Greeks were forced to try to figure things out.

Thales said: "The Babylonians and Egyptians seem to agree that in the beginning there was nothing but water. I myself feel that water is alive. Therefore, everything must have come from water."

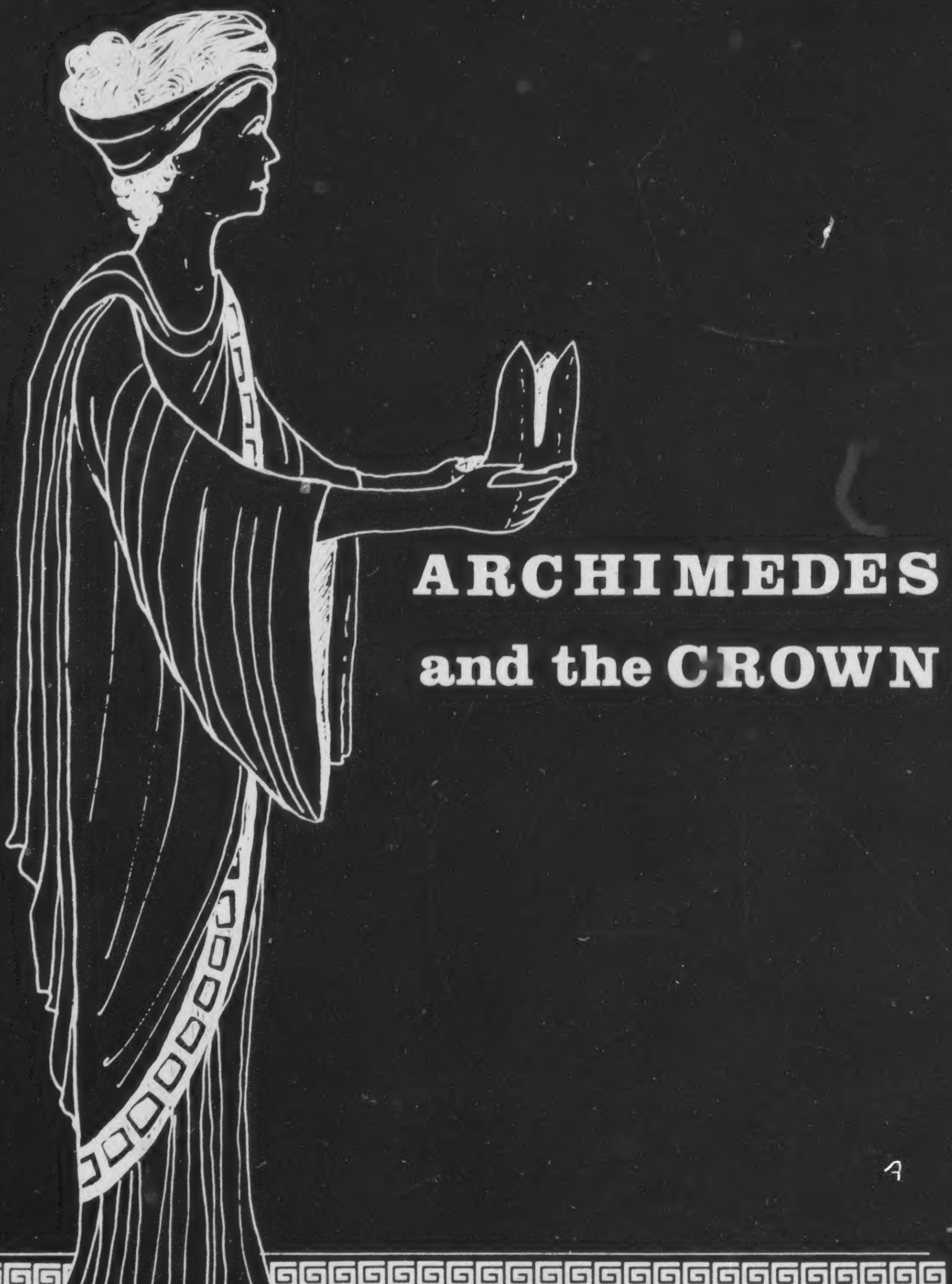
But other people did not see nature in quite the same way as Thales. They admitted that the general idea was a good one, so they accepted part of it and then tacked on something of their own.

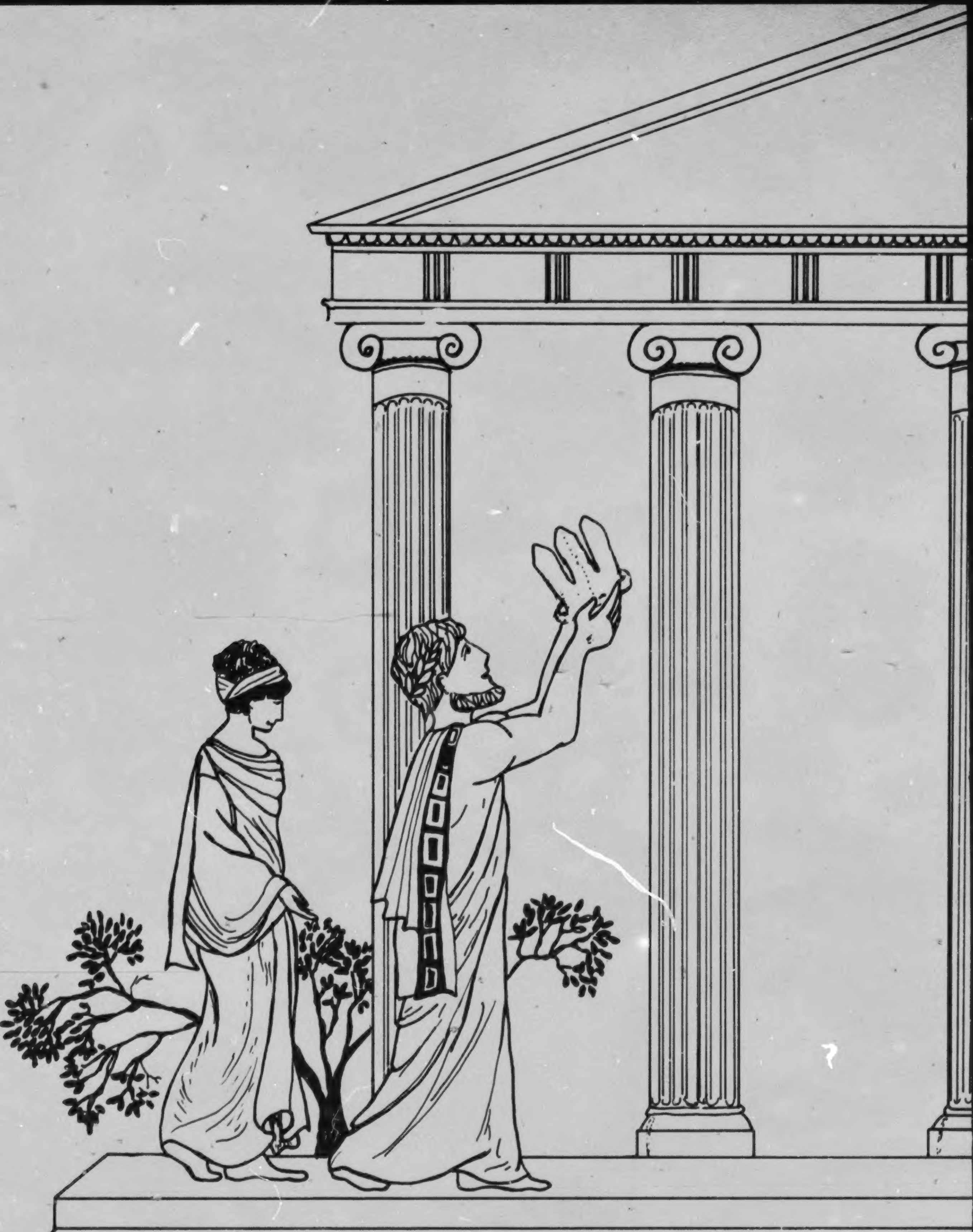
The trouble with this kind of reasoning was that if you didn't start with something that was solid and known, the whole set of ideas might not have much value. It was like building a beautiful house on a mud foundation. The mud would crumble away and when it did the whole house would fall down.

If you have a theory or an idea in science you must be able to test it. And that was what was good about the work of Anaxagoras. He found experiments to test his theory about air. And ever afterward people who knew about his experiments would know and could prove that there is air and that it takes up a certain amount of space. Later, someone else could build on this idea and find out something new.

So, the next time you have a bright idea or want to make a guess about something, try to find some way to test your idea by an experiment that will tell whether or not you are on the right track.

ARCHIMEDES and the CROWN



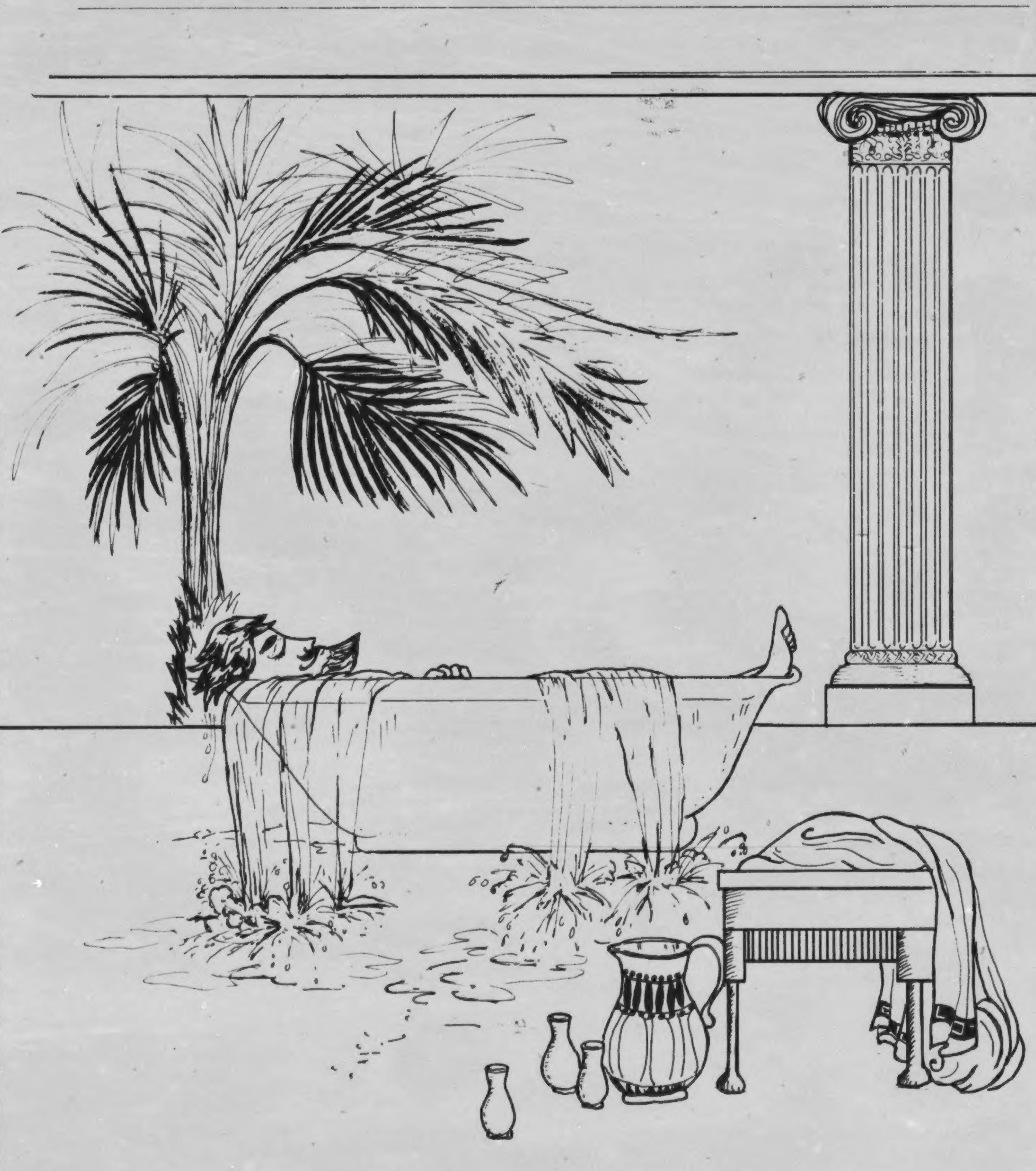


ARCHIMEDES

Long, long ago before there was any place called New York, London, or Paris, and when even Rome was little more than a town, one of the largest and most flourishing cities in the whole world was Syracuse on the Island of Sicily. This was more than two thousand years ago when the people of Syracuse were mostly Greeks and were ruled by a king named Hieron.

The story goes that Hieron decided to present a golden crown to the gods in order to show them how grateful he was for the good luck and happiness which he and his people had enjoyed during his long reign. Therefore he weighed out an exact amount of gold and gave it to the goldsmith who was to make the crown. After a while, the goldsmith returned with the finished product. It was very handsome, but Hieron was a cautious man and insisted on weighing the crown – just to be sure that the goldsmith had used all the gold. The test was made, and everything seemed to be in order: the crown had exactly the same weight as the amount of gold which Hieron had given the goldsmith to start with.

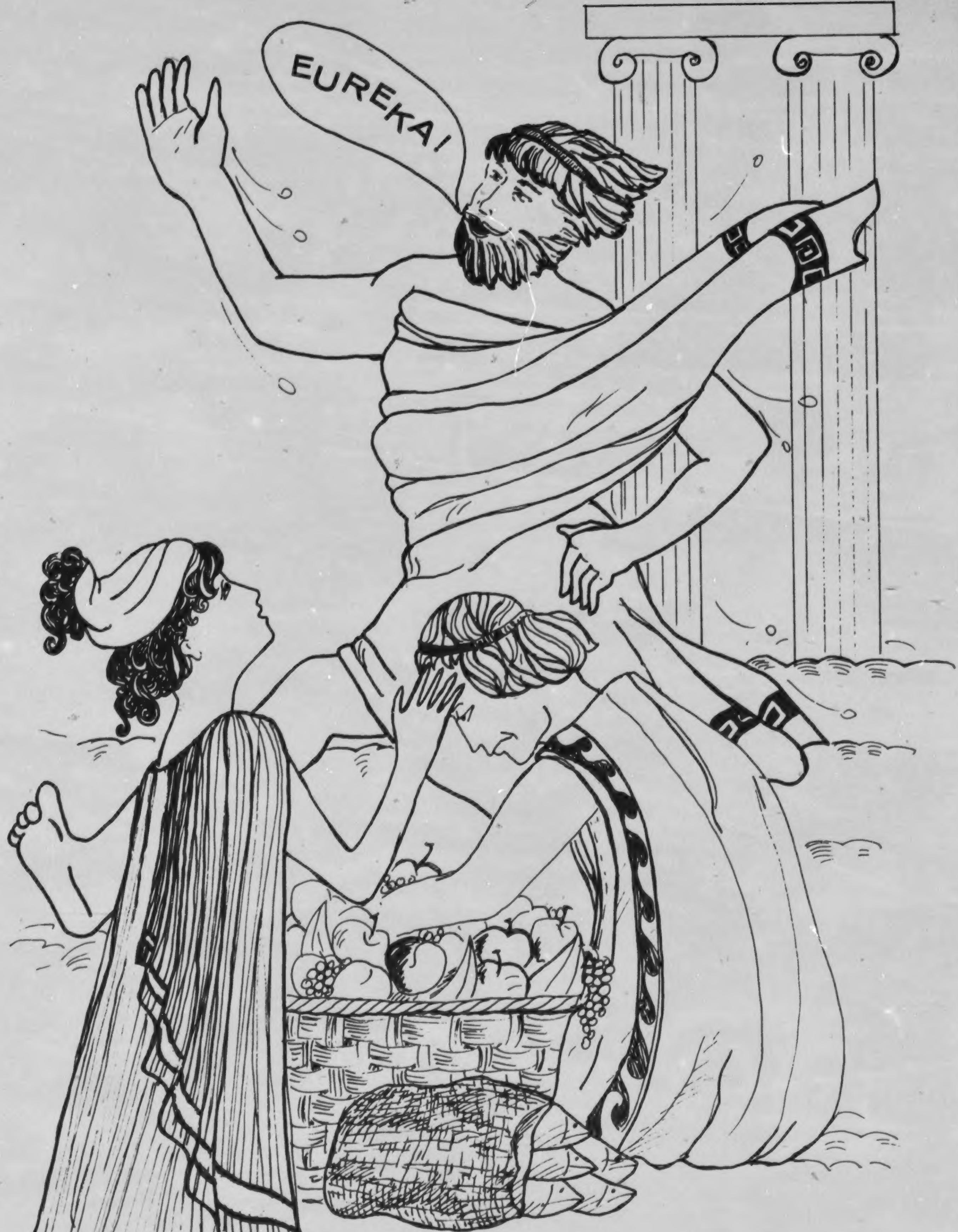
But this wasn't the end of the matter at all. Later on, gossip began to be heard in Syracuse that the crown was not pure gold, that the goldsmith had cheated the king by keeping some of the gold and using silver in its place. When he learned about this, Hieron was not pleased. In fact, he was quite angry, but how was he to discover the truth? He had already weighed the crown and found nothing wrong. What else could be done?



Portrait of Hieron on Greek coin

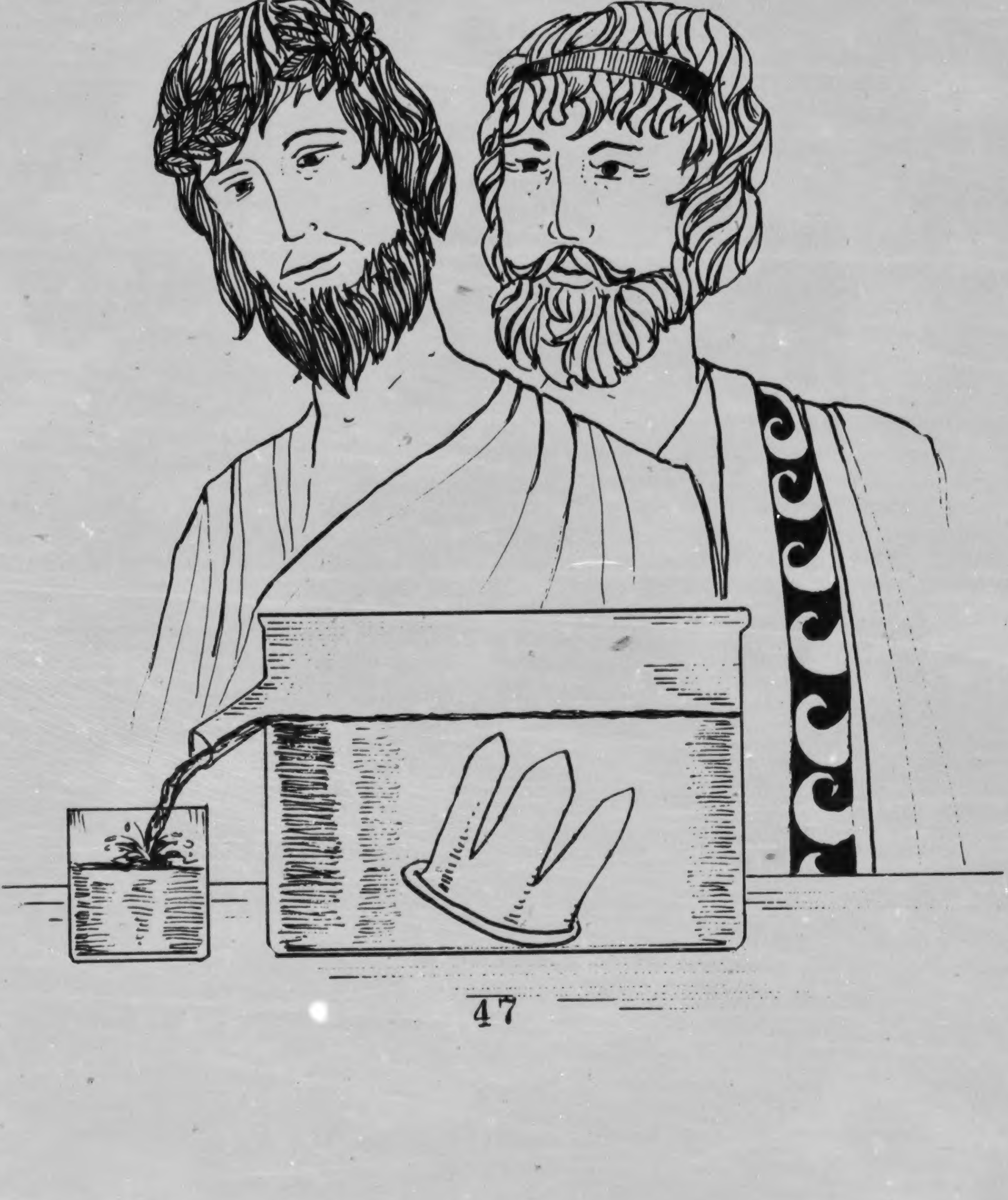
At last, Hieron consulted one of his relatives, a great scientist named Archimedes.

The problem wasn't an easy one, even for Archimedes. The more he thought about it, the more hopeless it seemed. Then, one day Archimedes went to the public baths, a kind of community swimming pool and bathing place. While relaxing in the water and thinking about his problem, Archimedes noticed that the more his body sank into the water, the more water ran over the side of the tub. In a flash the whole thing was clear to him: he had found a way to solve the puzzle of the crown!

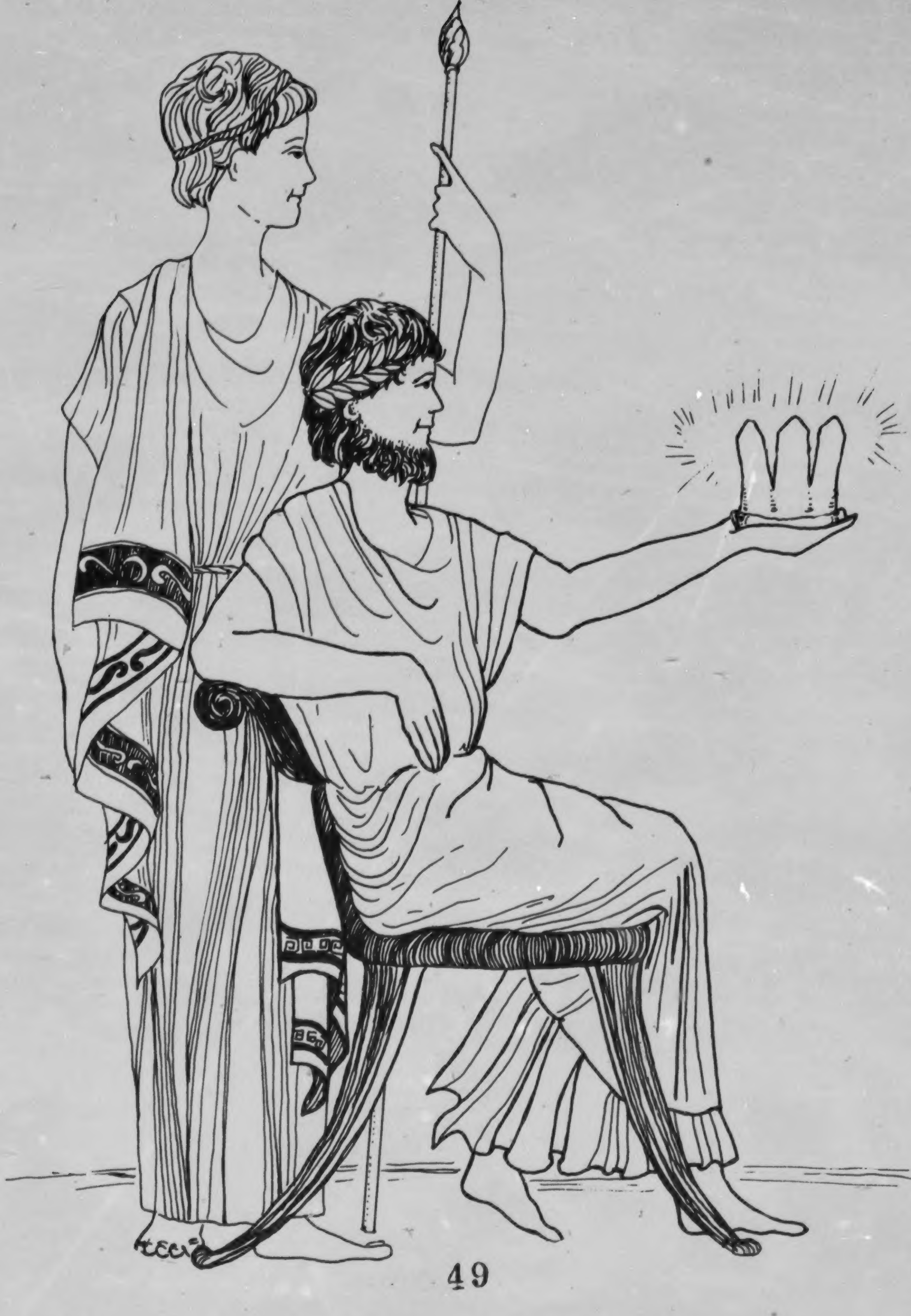

EUREKA!

In great excitement, Archimedes jumped out of the bath and ran for home through the crowded streets of Syracuse. As he ran, he shouted "Eureka! Eureka!" which in Greek means "I have found it!"

This created quite a stir. It was startling enough to see the one-man stampede of Archimedes through the streets and to hear his wild shouting, but there was an added and special feature that people never forgot: Archimedes had left all his clothes behind at the bath!



Well, when things had quieted down a bit, Archimedes performed an experiment. He took two lumps of metal, one of gold and one of silver, each of which had the same weight as the crown. Then he filled a large vessel with water, dropped in the lump of silver, and measured the volume of water that ran over the side. After this he did the same thing with the lump of gold, and he found that less water was



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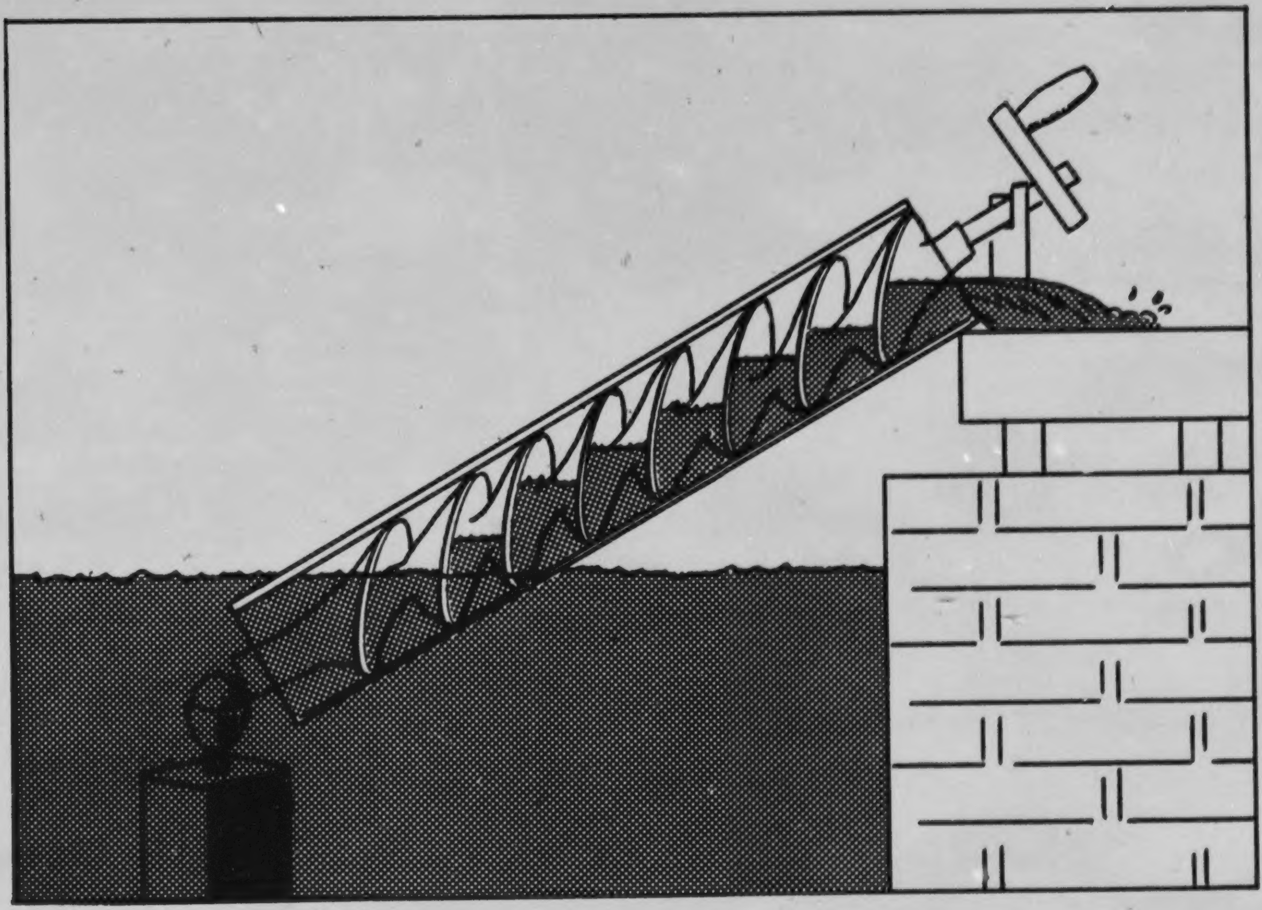
displaced by the gold than by the silver. The reason for this, of course, is that the density of gold is greater than that of silver; or, to put it another way, gold is more compact than silver. When at last Archimedes tested the crown itself in the same manner as his lumps of gold and silver, he discovered that the crown displaced or spilled over more water than the gold and less than the silver. Thus, he was able to prove to Hieron that the crown was indeed an alloy, that it contained both gold and silver.

* * * * * * * *

Now, this story about Archimedes and the crown may be only a story or, perhaps we should say, a legend. We know some of the other stories the Greeks and Romans told about Archimedes, and several of these are definitely "tall tales." On the other hand, we do know from the writings of Archimedes himself that he had the knowledge necessary to solve the problem of the crown. Also, we can be quite sure about some of his other successes.

Archimedes had many talents and interests: he was a great mathematician, an extraordinary physicist, and an astronomer of some ability. He was, for example, one of the few people of his time to accept the theory that the earth and the planets revolve about the sun. He even made a planetarium which demonstrated these movements and showed how eclipses occur. Archimedes was also interested in what we call the science of optics: he put together a complex system of mirrors which could concentrate the rays of the sun upon



Archimedes screw

a point and start a fire. This we can show from his own writings, but we don't have to believe the legend that his mirrors could set fire to enemy ships a long distance off.

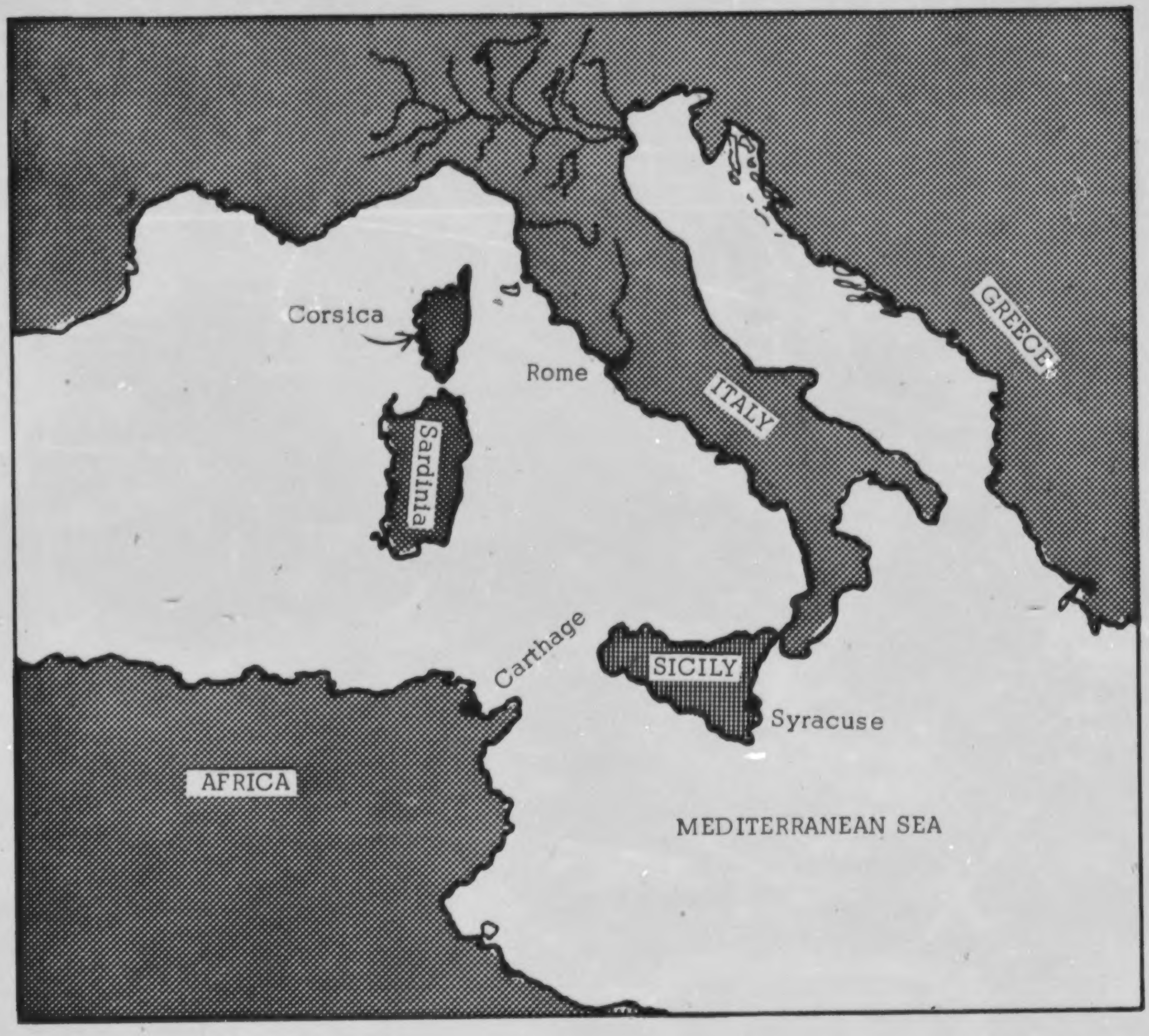
Some day, when you are older, you will probably read about the wonderful things that Archimedes did in geometry and physics. You will also discover that he was an inventor. He created machines, sometimes to aid his work in pure science and sometimes for more practical purposes. He invented an irrigation machine called the "screw" which raised water from one level to another. As a matter of fact, the "Screw of Archimedes" is still used in Egypt and some other parts of the world. With another of his machines, called the "helix," Archimedes almost single-handed was able to pull from the land into the water a huge sort of ocean liner which had been constructed for King Hieron. This ship, incidentally, was the largest ever built in ancient times. It could carry an enormous cargo as well as hundreds of passengers and sailors. It was so big that it couldn't sail into any of the harbors in Sicily, so Hieron made a present of it to the King of Egypt who did have a deep harbor at Alexandria.

A master of machines like the helix that used the principle of the lever, Archimedes boasted:

ΠΩ ΒΩ ΚΑΙ ΚΙΝΩ ΤΑΝ ΓΑΝ

PO BO KI KENO TAN GAN

"Give me a place to stand and I will move the earth!"


Corsica
Rome
GREECE
ITALY
Sardinia
Carthage
SICILY
Syracuse
AFRICA
MEDITERRANEAN SEA

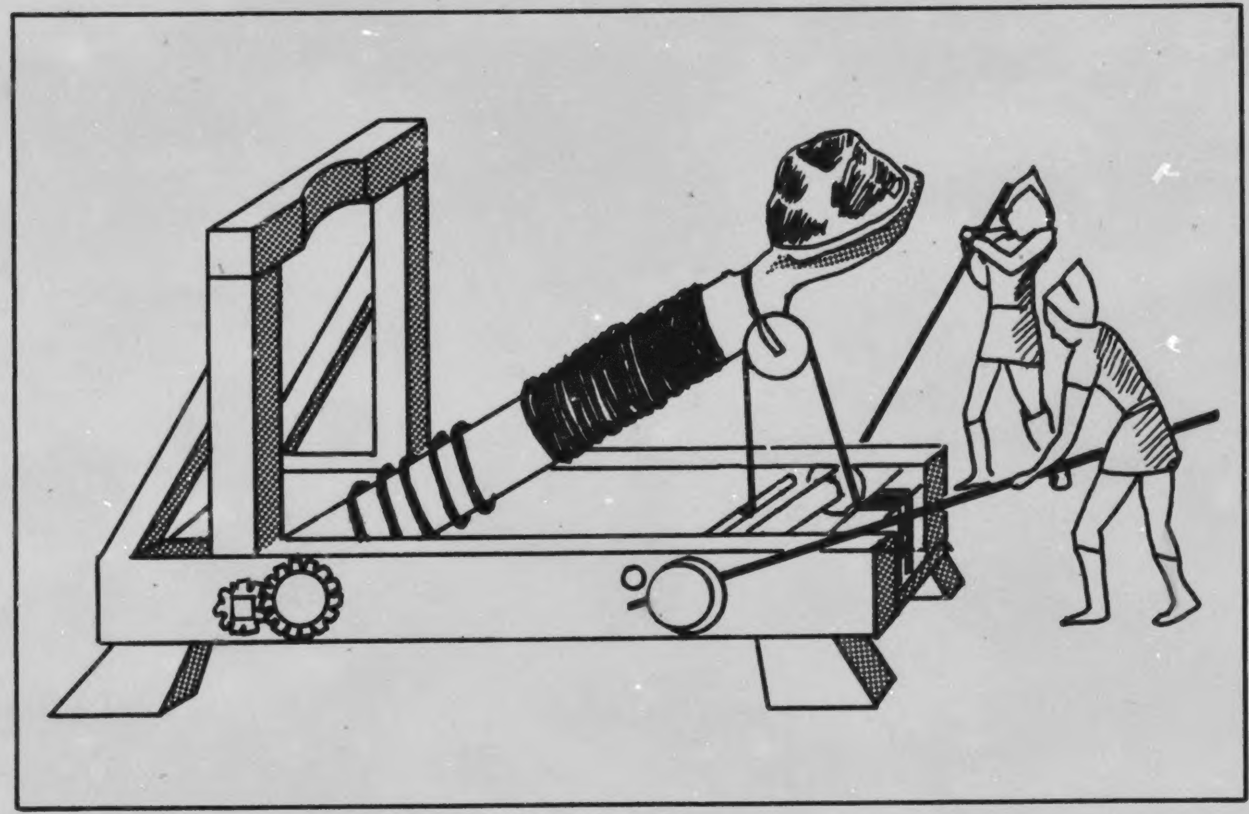
Location of cities at the time of Archimedes

Archimedes lived to be a very old man, to about the age of 75, and he ended his career, one might say, in a blaze of glory.

This story is true:

The Romans and the people of Carthage in North Africa were enemies and fought each other in several great wars. The people of Syracuse disliked the Carthaginians just about as much as the Romans did, and so they were Roman allies in the first two wars. The second war (Second Punic War, 218-201 B.C.) was the bitterest of all. This was the war in which Hannibal, the great Carthaginian general, marched from Spain, through France, and into Italy, crossing the Alps in deep snow with his war elephants. As Hannibal defeated the Romans in battle after battle in the early years of the war, people began to think that Rome would surely be defeated and her power destroyed. And, when things seemed most hopeless for Rome, King Hieron of Syracuse, a faithful Roman ally, died of old age, and his people broke off their alliance with Rome to join the Carthaginians on what appeared to be the winning side.

Although they were hard pressed by Hannibal in Italy and had lost many soldiers fighting his brother in Spain, the Romans could not afford to let the unfaithful Syracusans go unpunished because this might encourage other Roman allies in Sicily and South Italy to join the Carthaginians. Therefore, a great Roman fleet and army were sent to capture Syracuse. A siege followed that might have ended very quickly with the taking of Syracuse



Catapult

if it had not been for the skill of Archimedes who defended his city with marvelous engines of war that kept the Romans at bay for several years.

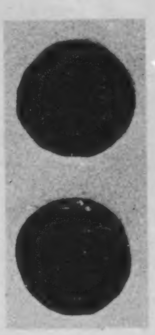
Because Syracuse had high, strong walls of stone on the landward side, the Romans concentrated their attack on the sea walls. Archimedes, however, had made machines, called catapults, which threw huge stones with great accuracy at both long and short range. These severely damaged the Roman warships which had been hovering offshore for the attack. Then, when the Romans tried to storm the walls by mounting towers on their ships and sailing right up to the fortifications, Archimedes fooled them again. Great beams of wood suddenly appeared over the tops of the walls. Hanging from these beams were huge weights that swung and smashed against the wooden scaling towers mounted on the ships. Other beams rigged with pulleys and counterweights let down claws that took hold of the prows of the Roman ships; when the counterweights were dropped to the ground inside the walls, the Roman ships were jerked high into the air; then the claws let go, and the ships fell and were splintered on the rocks below.

Archimedes had not boasted in vain about the lever. His machines were so terrible that the frightened Romans refused to fight against them. It was said that after this whenever the Romans saw even a piece of rope dangling from the walls, they would flee in panic.

But the siege went on. The Romans simply surrounded Syracuse and sat down to wait until the people ran out of food and had to surrender. In the end, Syracuse was captured, and in the looting, burning, and confusion of the taking of Syracuse, Archimedes was killed in spite of orders from the Roman commander that his life should be spared.

There were several stories about the death of Archimedes. According to the most common one, a Roman soldier came upon an old man who was studying a geometrical figure which he had drawn in the sand. Ordered to come along at once as a captive, the old fellow refused to move until he had finished working out his problem. The soldier, not realizing that his prisoner was Archimedes, drew his sword and killed him with a single blow.

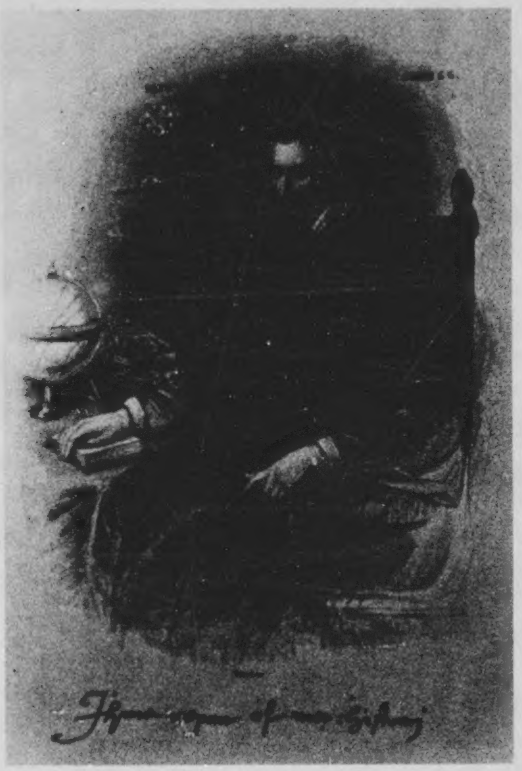
So died Archimedes, but he was never forgotten. Ever after scholars were to read and marvel at his writings, and the stories about Archimedes grew and grew until they weren't true any more and became instead the legend of Archimedes and his miracles of science.



Roman coin

NAPER'S BONES

An explanation of the different spellings of Napier's name is given on page 60.



John Napier

"NAPER'S BONES"

Set high upon a cliff, Fastcastle is an ancient fortress that broods over the angry waters of the North Sea. Long ago, on a dark, stormy night as bitter winds screamed and tugged at the towers of this haunted place, three men armed with flickering torches prowled through its vast chambers. One man was an outlaw who had sworn to kidnap the king. Another was a bold robber, the owner of the castle, who had often hidden the outlaw from the king's men. The third man, the one with the great black bird sitting on his shoulder, was said to be a warlock, a male witch. This third man, with his pointed beard and snapping black eyes, was clearly the leader of the mysterious expedition. Holding a forked willow stick in his two hands, he moved slowly from room to room. A stick of this kind is called a divining rod. It was used – it is still used – by the country people to find underground water, to locate the proper site for digging a well. But the bearded man was not in search of water; instead, he watched for the single end of his forked stick to dip and point to the spot where a chest of gold had been buried centuries before within the castle. If he could find this treasure, the others had promised him a third of it as his share.

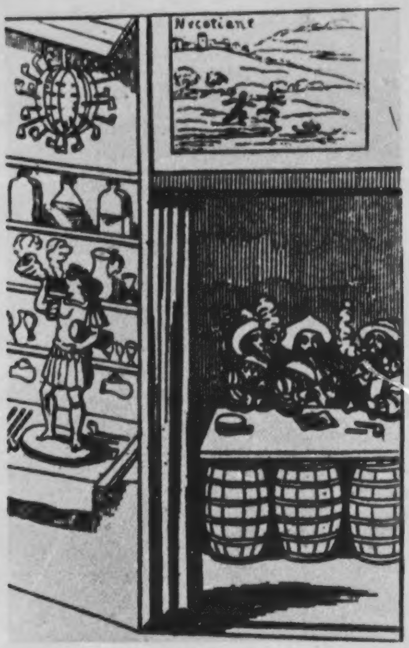
All of this happened in Scotland nearly four hundred years ago. In those days people believed in witches, black magic, and the Devil. The king himself, the one threatened by the outlaw, was a firm believer in such things. The king's name, by the way, was James. Later on, he would become King of England as well as Scotland and command his learned men to translate the Bible into English: this would be the famous King James Version of 1611.

But this was yet to come. When the three treasure seekers roamed through Fastcastle, James was merely King of Scotland while England was ruled by Elizabeth, Good Queen Bess. These were the days of Sir Walter Raleigh, Sir Francis Drake, and the Spanish Armada. Sir Francis Drake was one of the greatest of the "sea dogs," and he was also the first Englishman to sail around the world. Sir Walter Raleigh, you may remember, tried to establish an English settlement, Roanoke Colony, on an island off the coast of Virginia and later sailed off on a wild goose chase to South America searching for El Dorado, the legendary "Golden Man." Both Drake and Raleigh served Queen Elizabeth against the Spanish Armada in 1588 when the Spaniards tried to invade England with their huge navy only to be defeated and driven off forever. After Elizabeth had died, poor Sir Walter did not fare so well; King James sent him to the Tower of London and there chopped off his head.

These were the days of the great religious wars in Europe when the Protestant sects were beginning to appear, when Catholics and Protestants spent much of their time and energy trying to kill one another. The mother of King James — Mary, Queen of Scots — had often been scolded by the Presbyterian John Knox because she was a Catholic, and partly because of her faith poor Mary had been carried off

Mary, Queen of Scots

to England and beheaded there by order of her distant relative, Queen Elizabeth. King James, however, was a Protestant with very strong opinions about religion and other things besides. In an age of strong opinions, his were notorious for the force with which he expressed them. To cite one example, the use of tobacco was just coming into fashion in England and Scotland. James disapproved of smoking and set forth his views in a pamphlet entitled, "A Counterblast against the Vile Weed."



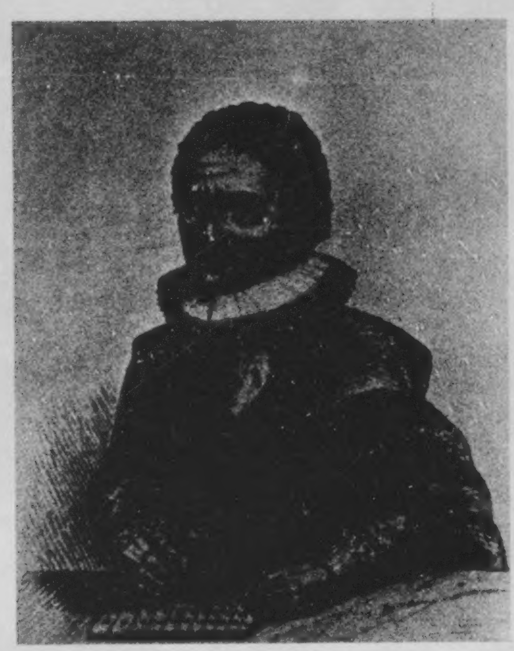
English tobacco shop during the reign of King James

James wrote much, mostly about religious matters, but he was not alone. The black-bearded warlock who had been engaged to find the treasure of Fastcastle by his magic powers was also a famous author. He was known throughout the British Isles and Europe for a book of prophecy based on a long study of the Bible and called "A Plaine Discovery of the Whole Revelation of St. John." Among other things, the book contained a prediction that the world would come to an end in about one hundred years.

Our hero was, in fact, regarded by everyone as a very religious man and extremely loyal to King James, yet there he was in Fastcastle consorting with two enemies of the king and practicing the blackest of black magic.

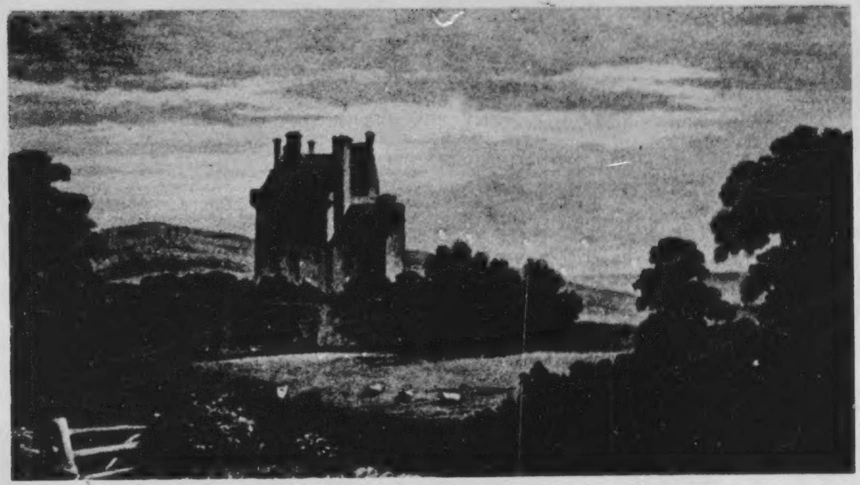
So, it was an age of contradictions as well as an age of strong opinions, and the final contradiction, the most incredible of all, was this: our loyal-disloyal, pious warlock was a scientist of some merit and a truly great mathematician. Like Archimedes and Newton, he will never be forgotten. His name was John Napier.

John Napier was born in 1550. Both his father and mother came from families that had been important in Scottish affairs for generations. John was their first child, born to them when they were sixteen years old. Archibald, the father, was to become Master of the Mint under King James. This meant that he was in charge of the coinage of money in Scotland and also responsible for the mines of the kingdom. He was very successful in finding small deposits of gold ore here and there, so much so that people thought he had some magical powers. This was probably one reason why his son, John, had been asked to locate the hidden treasure of Fastcastle.



Portrait of John Napier

As for John Napier, little of his early life is known. When he was thirteen, he went to study at the famous Scottish university of St. Andrews. He stayed there less than three years but may have continued his education in France at a later time. John Napier married when quite young, and, after the death of his first wife, he married again. From these two marriages he was to be the father of twelve children. Finally, when Archibald Napier died, John succeeded him as Baron Napier and went to live at Merchiston, the family castle situated not far from Edinburgh.



Merchiston Castle

John Napier lived until 1617, and it is the latter part of his life that is most familiar to us. The episode at Fastcastle took place in 1594, the year after the publication of the book on the Revelations of St. John. This was a tense period, full of anxiety and fear because the Spaniards were believed to be preparing another invasion attempt, directed this time against Scotland. Spain was a Catholic nation, while the people of Scotland were divided in their religious loyalties: James was a Protestant king, but many of his nobles were Catholics who might be willing to cooperate with the Spaniards in order to topple James from his throne.

How could the Scots defend themselves? John Napier turned his mind to engines of war; after some experiments, he reported to King James that he had several inventions that might be useful. He had made, he said, "burning glasses" like those of Archimedes which could concentrate the rays of the sun upon a distant point and set fire to enemy ships. He also claimed to have produced some new and deadly kind of artillery with unheard of fire power and also a "metal chariot," or tank as we would call it today. In addition, Napier spoke of experiments with warships that could sail under water – like our submarines. But the Spanish invasion did not come, and Napier's inventions were never put to use or even, so far as we know, tested.

Why, then, is John Napier famous today? The answer is that, unlike his inventions, his discoveries in mathematics were so important that we still make use of them after four centuries. Some of his achievements might be described as follows:

Nowadays when we go shopping, we look not only at the object or material we want to buy, but also at the price tag. Something may be priced at $2.99; something else at $1.10; or another thing at $6.75. We know that the number on the left tells us the price in dollars and the figures to the right the price in cents, or fractions of a dollar. Dollars and cents are divided by a symbol that looks like a period but which we call a decimal point. It was John Napier who first used the decimal point. Other people had tried more awkward and complicated means of separating the units from the decimal fractions, but Napier's method proved the simplest and best, and so it is still used today.

People then, just like people now, often found arithmetic very hard. Although addition and subtraction were usually not troublesome, multiplication and division were difficult and frequently time-consuming. It was always a struggle, for example, to learn the multiplication table. 2 x 2, 3 x 4, or even 5 x 5, came easily enough, but sometimes people could not remember 9 x 6, 8 x 7, or similar combinations toward the end of the table.

John Napier became interested in arithmetic and its difficulties. As he tried to think of ways to make it easier for people to learn, he began to write another book. He called it De Arte Logistica. These words are Latin; we might translate them, "Concerning the Art of Calculation." As a matter of fact, Napier's whole book was written in Latin mainly because Latin was then a language which all educated people in England, Scotland, France, Germany, and other European countries could read. A Frenchman might not be able to read English, or a German would not understand Spanish, and so on, but Latin was a language they could all use, and Napier wanted to be able to communicate with everyone. In addition, it was quite possible that some people would not take a book very seriously unless it was written in Latin, but it was also true that if Napier had written his book in the kind of English then spoken in Scotland even Englishmen might have had trouble understanding it. They would have encountered unfamiliar words and strange spellings. Just to cite one example, John Napier usually spelled his own name "Jhone Naper."

Signature: Jhone Naper, Baron of Merchiston

Despite his good intentions, Napier's book was not published during his lifetime. Its handwritten pages were found and printed by one of his descendants two hundred years later, but what Napier had to say is still clear and interesting to us now. At one point, for example, he attacked the problem of the multiplication table and suggested a method by which a person who could not remember 9 x 6 or 8 x 7 might nevertheless work out the answer.

Let's suppose that you have forgotten 9 x 6. What do you do? First, you put the 9 above the 6 in a column like this:

9
6

Then, in a new column to the right of the first one, you put opposite the 9 the number that added to 9 will give 10; and beneath that, opposite the 6, you put the number that added to 6 will make 10. So:

9 1
6 4

Now multiply 4 x 1. That will give **4** . Next, subtract 4 from 9, or 1 from 6. In either case you will get **5** . Finally, take the **4** which is the product of 4 x 1 and the **5** which is the difference of 9-4 or 6-1. Write down the number that has 5 on the left and 4 on the right. This will be **54** , and that is the answer.

Let's try 8 x 7:

Step one **8**
7

Step two 8+2=10. 7+3=10

Step three **8 2**
7 3

Step four 2 x 3 = **6**

Step five 8-3=5 or 7-2=**5**

Step six Put **5** on the left and **6** on the right.

THE ANSWER IS **56**

Why don't you try 8 x 9, or 9 x 9? If you experiment, you will find that the method in its exact form can be used only for certain combinations:

5 x 9 (9 x 5)
6 x 8, 6 x 9 (8 x 6, 9 x 6)
7 x 7, 7 x 8, 7 x 9 (8 x 7, 9 x 7)
8 x 8, 8 x 9 (9 x 8)
and all combinations with 9 from 9 x 1 to 9 x 9

PROBLEM	STEPS					ANSWER
	①	②	③	④	⑤	
9 x 2	9 2	9+1=10 2+8=10	9 1 2 8	1x8=8	9-8=1 2-1=1	18
9 x 9	9 9	9+1=10 9+1=10	9 1 9 1	1x1=1	9-1=8 9-1=8	81
7 x 6	7 6	7+3=10 6+4=10	7 3 6 4	3x4=12	7-4=3 6-3=3	3 12 42
8 x 3	8 3	8+2=10 3+7=10	8 2 3 7	2x7=14	8-7=1 3-2=1	1 14 24

If, however, you want to modify the method, it can be used for other combinations. You can see for yourself what must be done if you can't remember 6 x 7. You will have:

$$\begin{array}{cc} 6 & 4 \\ 7 & 3 \end{array}$$

4 x 3 = 12, but 6-3 or 7-4 = 3 so you must do this:

$$\begin{array}{r} 12 \\ +\ 3 \\ \hline 42 \end{array}$$

Moreover, if you experiment further, you will discover that the method will not help you to find 8 x 2, 7 x 3, 6 x 4, or 5 x 5. In other words, the method is not a substitute for memorizing the multiplication table. Napier assumed that people would have learned the combinations from 1 x 1 through 5 x 5, or at least the part of the table outlined in black in the figure below.

	1	2	3	4	5	6	7	8	9
1	1	2	3	4	5	6	7	8	9
2	2	4	6	8	10	12	14	16	18
3	3	6	9	12	15	18	21	24	27
4	4	8	12	16	20	24	28	32	36
5	5	10	15	20	25	30	35	40	45
6	6	12	18	24	30	36	42	48	54
7	7	14	21	28	35	42	49	56	63
8	8	16	24	32	40	48	56	64	72
9	9	18	27	36	45	54	63	72	81

The De Arte Logistica was an early attempt by Napier, and perhaps one reason why he failed to publish it was that he continued to find new ways of making arithmetic easier. Eventually, he devised a sort of computer. You can make one like it for yourself by cutting out ten strips of cardboard and marking them as follows:

Strip A	Set B								
1	1	2	3	4	5	6	7	8	9
2	/2	/4	/6	/8	1/0	1/2	1/4	1/6	1/8
3	/3	/6	/9	1/2	1/5	1/8	2/1	2/4	2/7
4	/4	/8	1/2	1/6	2/0	2/4	2/8	3/2	3/6
5	/5	1/0	1/5	2/0	2/5	3/0	3/5	4/0	4/5
6	/6	1/2	1/8	2/4	3/0	3/6	4/2	4/8	5/4
7	/7	1/4	2/1	2/8	3/5	4/2	4/9	5/6	6/3
8	/8	1/6	2/4	3/2	4/0	4/8	5/6	6/4	7/2
9	/9	1/8	2/7	3/6	4/5	5/4	6/3	7/2	8/1

Now suppose that you want to multiply 75 x 93. Take your B-7 strip and your B-5 strip and place them side by side as shown in the drawing below and put Strip A at the far right. Next, look at the 3 line indicated by arrow no. 1. Here you see 2/1 and 1/5. This is to be read 2, 1+1, 5, or 225. This is the product of 75 x 3. Now, look at the 9 line indicated by arrow no. 2. Here you see 6/3 and 4/5. This is to be read 6, 3+4, 5, or 6750 because this is the product of 75 x 90. The reason for adding the 0 to 675 is that 93 is, after all, 90 + 3. Finally, we add 225 and 6750 to get our answer which is 6975.

Let's take another example: 75 x 7. Look at the 7 line in the drawing where you will see 4/9 and 3/5. This is to be read 4, 9+3, 5, or 4, 12, 5, or finally 525 because the 1 must be carried over and added to the 4. Similarly, 75 x 4 would give 2/8 and 2/0 and read 2, 8+2, 0, or 2, 10, 0, or finally 300.

75 x 93

7	5	1	
1/4	1/0	2	
2/1	1/5	3 ← ①	2, 1+1, 5 = 2 2 5
2/8	2/0	4	
3/5	2/5	5	
4/2	3/0	6	
4/9	3/5	7	
5/6	4/0	8	
6/3	4/5	9 ← ②	6, 3+4, 5 = 6 7 5 0

$$\begin{array}{r} 2\ 2\ 5 \\ +\ 6\ 7\ 5\ 0 \\ \hline 6\ 9\ 7\ 5 \end{array}$$

7	5		
4/9	3/5	7 ←	4, 9+3, 5 =

$$\begin{array}{r} 5 \\ 1\ 2\ \ \\ 4\ \ \ \ \\ \hline 5\ 2\ 5 \end{array}$$

7	5		
2/8	2/0	4 ←	2, 8+2, 0 =

$$\begin{array}{r} 0 \\ 1\ 0\ \ \\ 2\ \ \ \ \\ \hline 3\ 0\ 0 \end{array}$$

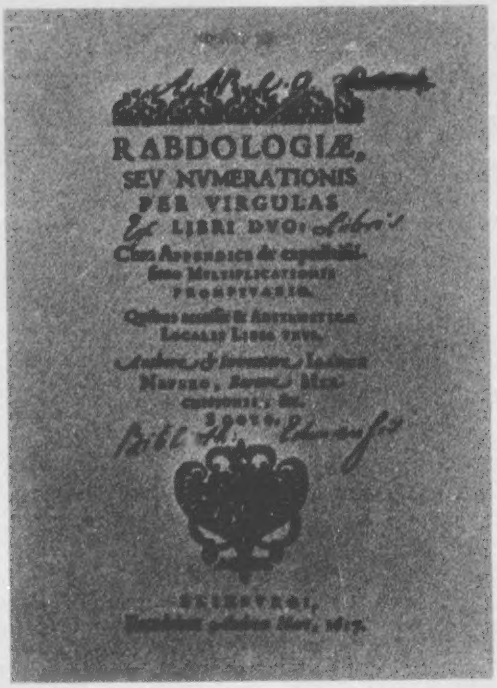
Let's take another example:

5124 x 689

5	1	2	4	1	
1/0	/2	/4	/8	2	
1/5	/3	/6	1/2	3	
2/0	/4	/8	1/6	4	
2/5	/5	1/0	2/0	5	
3/0	/6	1/2	2/4	6	← ③
3/5	/7	1/4	2/8	7	
4/0	/8	1/6	3/2	8	← ②
4/5	/9	1/8	3/6	9	← ①

$$\begin{array}{cr l} ① & 46116 & \\ ② & 40992 & \\ ③ & 30744 & \\ \cline{2-2} & 3530436 & \text{ANSWER} \end{array}$$

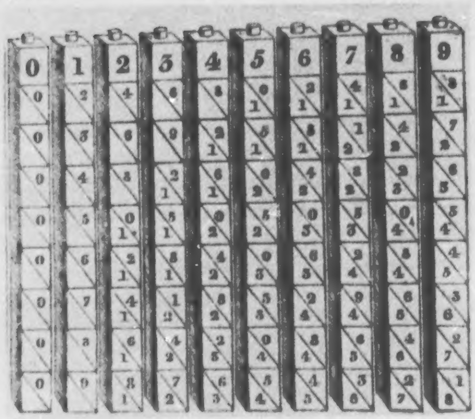
Napier's description of his "computer" was published in Latin in 1617. He called his strips "numbering rods." Made of wooden blocks or sometimes metal strips, instead of cardboard like yours, they were also known as "speaking rods," or more commonly, "Naper's Bones." Many people eagerly adopted this simplified means of computation, and the rods were used everywhere for years. Napier's book, the Rabdologia (Rod Calculation), was so popular that it was soon translated into English, Italian, and several other languages.



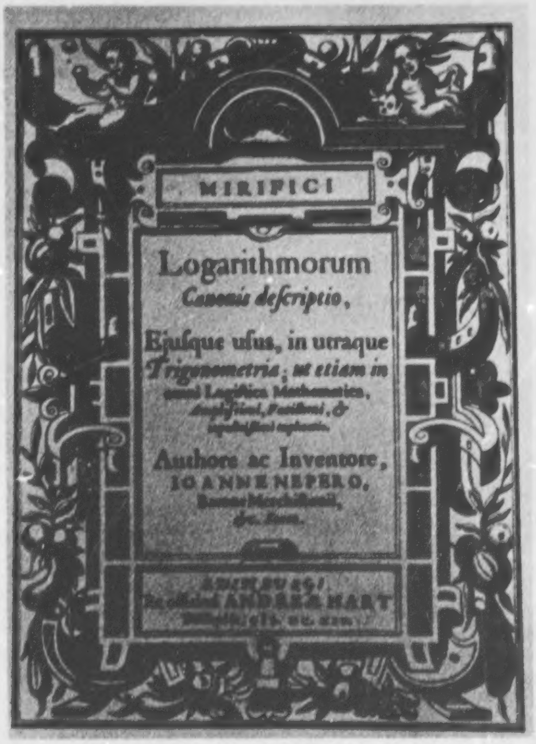
RABDOLOGIÆ,
SEV NVMERATIONIS
PER VIRGULAS
LIBRI DVO:

Title page from Rabdologia

"Naper's Bones"



Even this was not John Napier's greatest achievement. The De Arte Logistica and the Rabdologia had been intended to help ordinary people with their everyday problems of calculation, but there were astronomers, surveyors, architects, and, of course, mathematicians who had much more formidable problems to solve. Imagine having to deal endlessly with such computations as multiplying 9675482735 by 6588925463 and then having to divide that by 2565904391! By a great stroke of genius and long years of hard labor, Napier simplified all this by a marvelous invention, his Admirable Canon of Logarithms, as he called it, which appeared in print in 1614.



MIRIFICI

Logarithmorum
Canonis deſcriptio,

Ejuſque uſus, in utraque
Trigonometria; ut etiam in
omni Logiſtica Mathematica,

Authore ac Inventore,
IOANNE NEPERO,

Title page from
Admirable Canon of Logarithms

As you know, it is much quicker and easier to add or subtract numbers than to multiply or divide them, and there are fewer chances of making mistakes. Multiplication, as Napier put it, involved "a tedious expense of time" and was "subject to many slippery errors." Therefore, by developing his system of logarithms, or number ratios, Napier reduced multiplication to a matter of addition while division became subtraction. The problem given above:

$$\frac{9675482735 \times 6588925463}{2565904391}$$

which has the form $\frac{A \times B}{C}$ can be changed to "log A + log B - log C" by using a book of logarithmic tables. First, one finds in the tables the logarithms corresponding to the numbers A, B, and C. Then the logarithms of A and B are added and the logarithm of C subtracted from this sum. This will give a fourth logarithm (D) which, when located in the book of tables, will reveal the corresponding number that is the answer to the problem. An example of this kind of computation will be seen on the next page.

As an illustration of the use of logarithms, we might take a problem we have considered earlier — 5124 x 689 — and enlarge it to $\frac{5124 \times 689}{732}$.

A. Using ordinary methods of computation:

$$
\begin{array}{r}
5124 \\
\times\, 689 \\
\hline
46116 \\
40992 \\
30744 \\
\hline
3530436
\end{array}
$$

$$
\begin{array}{r|l}
732 & \overline{3530436}\ \ \underline{\underline{4823}} \longleftarrow \text{ANSWER} \\
 & \underline{2928} \\
 & 6024 \\
 & \underline{5856} \\
 & 1683 \\
 & \underline{1464} \\
 & 2196 \\
 & 2196
\end{array}
$$

B. Using the "bones"

5	1	2	4	
3/0	/6	1/2	2/4	6 → 30744
4/0	/8	1/6	3/2	8 → 40992
4/5	/9	1/8	3/6	9 → 46116

$$
\begin{array}{r}
46116 \\
40992 \\
30744 \\
\hline
3530436
\end{array}
$$

$$
\frac{3530436}{732}
$$

(The bones afford no shortcut to division, so we must use the ordinary method.)

C. Using logarithms:

LOG A + LOG B - LOG C = LOG D

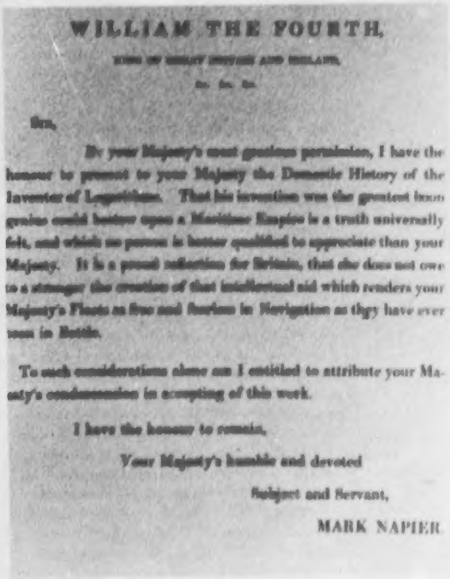
LOG	5124	3.7096091
+ LOG	689	+ 2.8382192
(LOG	3530436)	6.5478283
- LOG	732	- 2.8645111
LOG	D	3.6833172

LOG D is the corresponding logarithm of $\underline{\underline{4823}}$.

At any rate, the result of Napier's magnificent invention was that science and mathematics were able to move ahead by great strides, and the birth of our present Age of Science occurred far earlier than it might otherwise have done. Some day you will study logarithms and learn to use them, and you will probably also learn to use a device called a slide rule which is based on Napier's logarithms. Then you will appreciate much more fully what a great thing it was that John Napier did.

People have often wondered about the meaning of the name Napier. It is thought by some that Napier comes from "Na Peer" which might mean "without an equal." If this is so, this name would be especially appropriate for Baron John Napier, the inventor of logarithms, for whom it would indeed be very hard to find an equal.

John Napier



WILLIAM THE FOURTH,

KING OF GREAT BRITAIN AND IRELAND,

&c. &c. &c.

Sir,

By your Majesty's most gracious permission, I have the honour to present to your Majesty the Domestic History of the Inventor of Logarithms. That his invention was the greatest boon genius could bestow upon a Maritime Empire is a truth universally felt, and which no person is better qualified to appreciate than your Majesty. It is a proud reflection for Britain, that she does not owe to a stranger the creation of that intellectual aid which renders your Majesty's Fleets as free and fearless in Navigation as they have ever been in Battle.

To such considerations alone am I entitled to attribute your Majesty's condescension in accepting of this work.

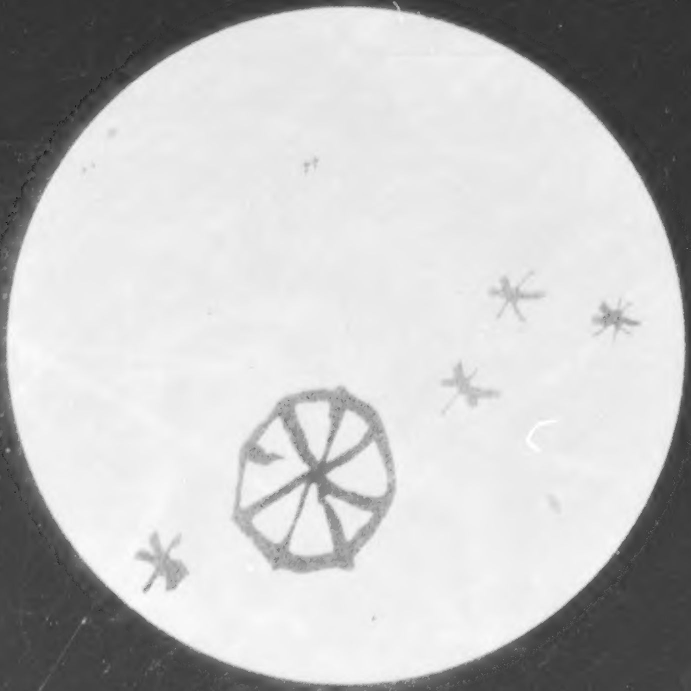
I have the honour to remain,

Your Majesty's humble and devoted

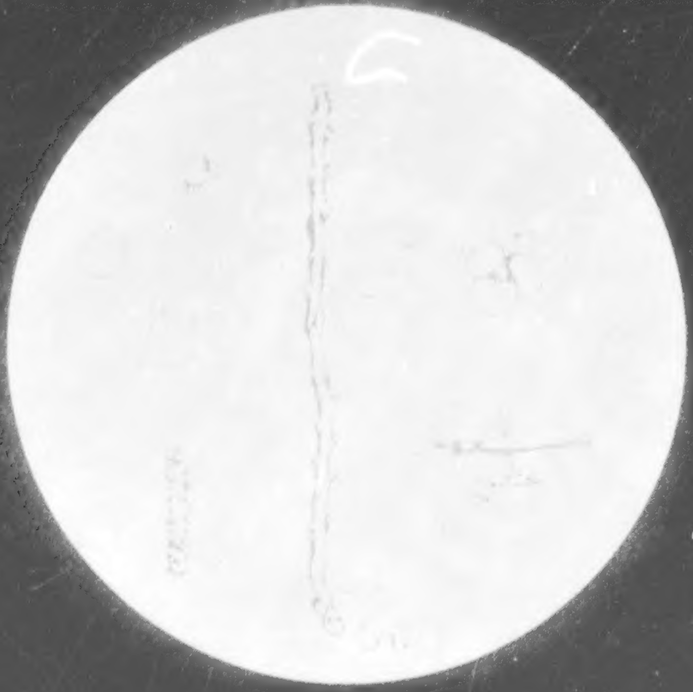
Subject and Servant,

MARK NAPIER

EXTENDING MAN'S SENSES



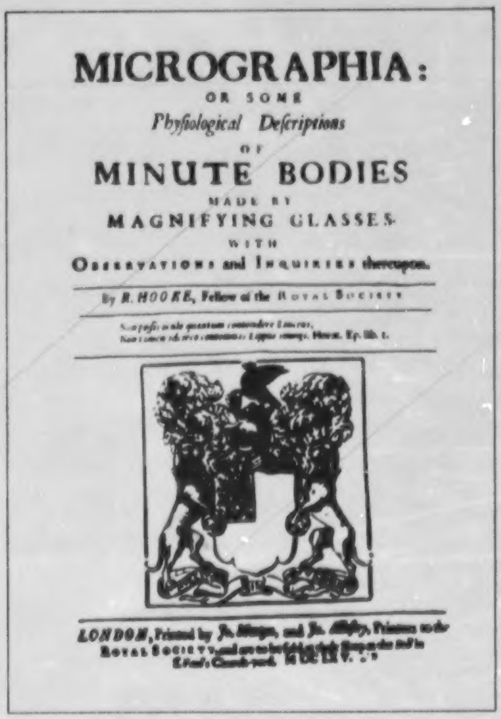
THE TELESCOPE AND THE MICROSCOPE



EXTENDING MAN'S SENSES

THE TELESCOPE AND THE MICROSCOPE

About three hundred years ago — in the very year, in fact, in which New Amsterdam became New York (1664) — a very talented English scientist named Robert Hooke was writing a book called Micrographia. Published in London in 1665, it bore the subtitle, "Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses." In his Preface, or introduction, Mr. Hooke said: "As for the actions of our senses, we cannot but observe them to be in many particulars much outdone by those of other creatures, and when at best, to be far short of the perfection they seem capable of ...."



MICROGRAPHIA:
OR SOME
Phyſiological Deſcriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES.
WITH
OBSERVATIONS and INQUIRIES thereupon.

By *R. HOOKE*, Fellow of the ROYAL SOCIETY

Title page from *Micrographia*
by Robert Hooke

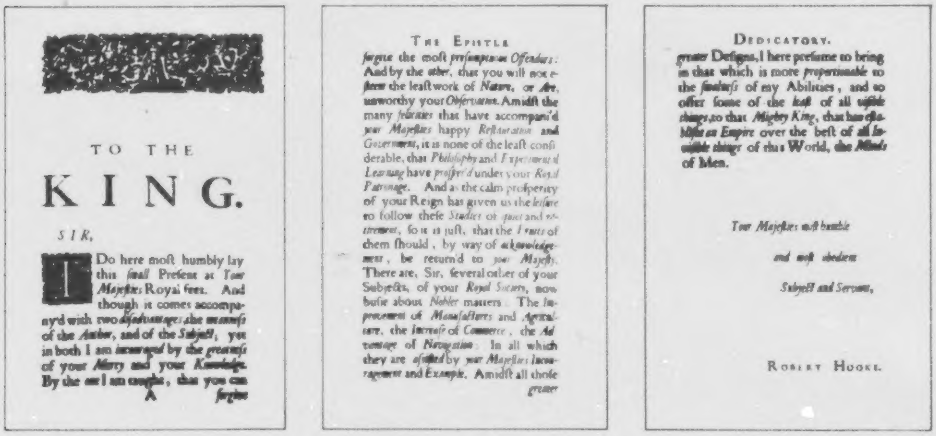
Hooke's point was that our senses can be improved or extended by means of instruments: "the adding of artificial organs to the natural; this .... has been of late years accomplished .... with benefit to all sorts of useful knowledge, by the invention of optical glasses. By means of telescopes there is nothing so far distant but may be represented to our view; and by the help of microscopes, there is nothing so small, as to escape our inquiry; hence there is a new visible world discovered .... By this means the heavens are opened .... By this the earth itself, which lies so near to us, under our feet, shows quite a new thing to us, and in every little particle .... we now behold as great a variety of creatures, as we were able before to reckon up in the whole universe itself."

Robert Hooke was right! "Optical glasses" had made it possible for men to see the world as they had never seen it before or even imagined it to be. It was almost as if the human race had always been blind and now had suddenly been given eyes. In Hooke's own lifetime the new aspect of the heavens revealed by the telescope had forced people to abandon age-old beliefs and adopt others quite different; man even had to find new ways of reasoning in order to explain what he now saw for the first time. No longer could it be imagined that the sun revolved about the earth, or that the earth was at the center of the universe. It came as a real shock to discover that the earth was only one of several planets in a relatively small solar system tucked away somewhere in a gigantic universe that might have no boundaries at all.

So much for the telescope. But what about its counterpart, the microscope, the possibilities of which were just beginning to be realized toward the end of Hooke's life? The microscope brought into view tiny living bodies, so small as to defy human understanding. The world revealed by the microscope would before long revolutionize the concept of disease, help make the practice of medicine a science, and eventually push man to the discovery of the innermost secrets of the living cell itself.

The first important discoveries with the telescope and microscope, the ones that set in motion the scientific upheaval which we have been describing, were made by two men. Both lived at least a part of their lives in the seventeenth century, the century of Robert Hooke; both were skillful observers; both were about 45 when their discoveries permanently inscribed their names upon the pages of history, and neither invented the instrument which he used with such success. Except for these similarities, however, these two men were quite different. One was an Italian; the other was a Hollander. One was a professor, a highly educated man; the other was a shopkeeper who never finished his primary schooling. One knew many languages, and moved in the society of nobles and princes; the other knew only Dutch and rarely saw any but his fellow townspeople. One was argumentative, controversial and proud of his ability; the other was modest, unassuming and very grateful to be noticed at all.

Who were these men? The Italian was Galileo Galilei; the Hollander was Antony van Leeuwenhoek.



TO THE

KING.

SIR,

I Do here moſt humbly lay this *ſmall* Preſent at *Your Majeſties* Royal feet. And though it comes accompany'd with two *diſadvantages*, the *meanneſs* of the *Author*, and of the *Subject*; yet in both I am *incouraged* by the *greatneſs* of your *Mercy* and your *Knowledge*. By the one I am taught, that you can

A *forgive*

THE EPISTLE

forgive the moſt *preſumptuous Offenders*: And by the *other*, that you will not eſteem the leaſt work of *Nature*, or *Art*, unworthy your *Obſervation*. Amidſt the many *felicities* that have accompani'd *your Majeſties* happy *Reſtauration* and *Government*, it is none of the leaſt conſiderable, that *Philoſophy* and *Experimental Learning* have *proſper'd* under your *Royal Patronage*. And as the calm proſperity of your Reign has given us the *leiſure* to follow theſe *Studies* of *quiet* and *retirement*, ſo it is juſt, that the *Fruits* of them ſhould, by way of *acknowledgement*, be return'd to *your Majeſty*. There are, Sir, ſeveral other of your Subjects, of your *Royal Society*, now buſie about *Nobler* matters: The *Improvement* of *Manufactures* and *Agriculture*, the *Increaſe* of *Commerce*, the *Advantage* of *Navigation*: In all which they are *aſſiſted* by *your Majeſties Incouragement* and *Example*. Amidſt all thoſe

greater

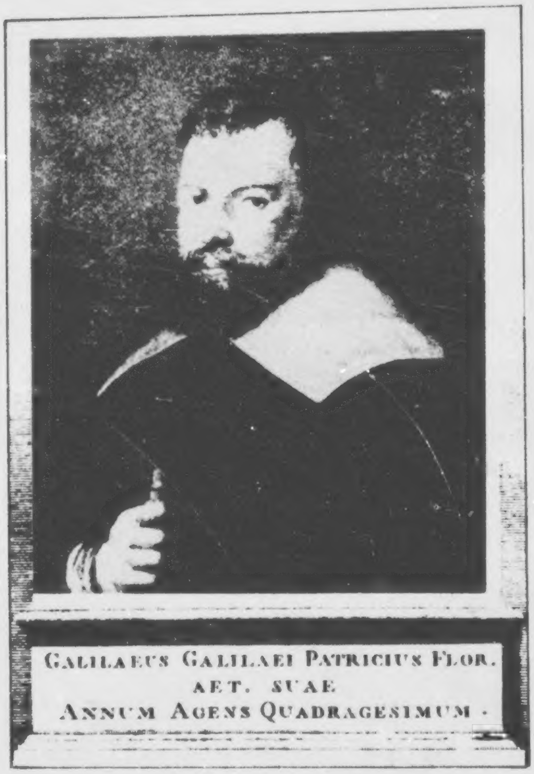
DEDICATORY.

greater Deſigns, I here preſume to bring in that which is more *proportionable* to the *ſmalneſs* of my Abilities, and to offer ſome of the *leaſt* of all *viſible things*, to that *Mighty King*, that has *eſtabliſht an Empire* over the beſt of *all Inviſible things* of this World, the *Minds* of Men.

Your Majeſties moſt humble
and moſt obedient
Subject and Servant,

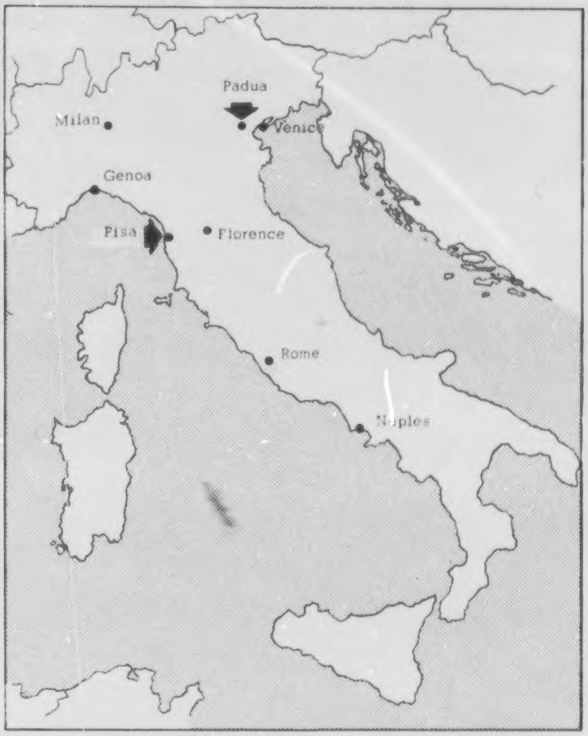
ROBERT HOOKE.

Dedication taken from Micrographia to King Charles II by Robert Hooke


GALILAEUS GALILAEI PATRICIUS FLOR.
AET. SUAE
ANNUM AGENS QUADRAGESIMUM .

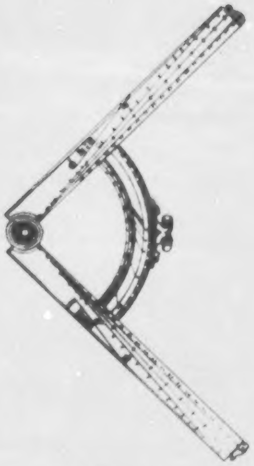
GALILEO

Galileo was born in Pisa in the territory of the Grand Duchy of Tuscany in northern Italy on February 15, 1564. His father was a musician, a performer and something of an authority on music as well. Galileo began his education in a monastery where he learned Greek and Latin and quite a bit about the literature of Italy. Then, because his father wished it, he studied medicine in the University of Pisa and graduated



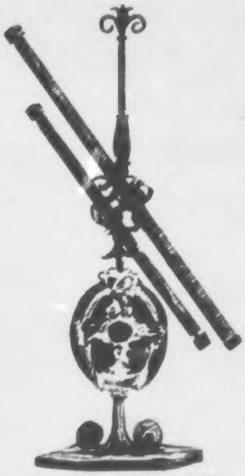
Map of Italy showing Pisa where Galileo was born and Padua where he taught at the University

in 1585 although he never became a full-fledged doctor or practiced as a physician. One of the reasons for this was that Galileo had been studying mathematics, particularly geometry, with a private teacher. He soon found that mathematics fascinated him, as medicine did not. Moreover, his progress was so rapid and exceptional that he was appointed to teach mathematics in the University of Pisa in 1589.



Warfare Instrument designed by Galileo

Galileo enjoyed his new position and his teaching, but the salary was very small. Consequently, when his father died in 1591 and he found himself responsible for the support of his mother and his brother and sisters, Galileo had to find a better job. In 1592 he moved to the University of Padua, in the territory of the Republic of Venice, where the pay was a little better and future prospects seemed brighter. Even so, Galileo was forced to do private teaching to make more money, and he also opened up a shop which sold mathematical apparatus. He did not make the instruments which he sold -- he was able to find skilled craftsmen to do that -- but he discovered that there was profit in inventing new instruments, particularly those useful in warfare.



Telescope designed by Galileo

Galileo's need for money and his interest in invention brought him to the telescope. In 1609 he heard of "a Dutchman who had constructed a telescope by means of which objects .... though distant .... were seen as if near." Although the stories about the new instrument were conflicting -- some people said it worked, and others said it didn't -- when Galileo got a letter from a friend in Paris who was enthusiastic about the telescope, he decided to "invent" one of his own. Presumably Galileo drew up the plans and then had the instrument made in his shop. "I first prepared a tube of lead," reported Galileo, "in the ends of which I fitted two glass lenses, both plane [flat] on one side, but on the other side one [lens] was convex, and the other concave." Finding that this first telescope was reasonably satisfactory, Galileo made improvements which were included in a second and more powerful instrument that was sold to the Republic of Venice. The Venetians were delighted. This was something useful in warfare: they could observe enemy troop movements and enemy ships when they were still miles away and not visible to the naked eye. In gratitude, they made Galileo professor for life and doubled his salary.

Now, Galileo did not invent the telescope. He made the first one to be seen in Venice, and he had probably never seen a telescope himself, although by 1609 telescopes were being displayed and sold in Holland, Paris, London, and perhaps even northern Italy. The new instruments were called "Dutch trunks," "perspectives," and "cylinders." Galileo called his an "occhiale;" the word "telescope" was not coined until about forty years later.

Telescope made by Hollanders in 1608

Actually, we do not know who invented the telescope. In 1608 three Hollanders made telescopes, and each one claimed the invention as his own. These men were Hans Lippershey, Jacob Adriaanzoon (also called Metius), and Zacharias Janssen. The last named probably did invent the compound microscope, which used two lenses like the telescope. (Incidentally, this Janssen was a very lively character who became a counterfeiter and narrowly escaped being boiled in oil, the customary punishment for such an offence.) However, the claims of Lippershey, Metius, and Janssen with regard to the invention of the telescope were, and still are, disputed. There was a story that a foreigner came to the shop of Lippershey and asked him to make a number of lenses, some concave and others convex. When the lenses were finished, the stranger came back and sat for some time looking through pairs of lenses, holding a concave lens at some distance from the convex one that was nearest his eye and also reversing these positions. Then he paid for the work and departed. Lippershey, the story goes, was fascinated by this and imitated what the stranger had done. He thus learned the principle of the telescope and made one of his own which he claimed as his invention.

On the other hand, there is still another tale of a man who said that he saw a telescope which had been made in Italy and bore the date, 1590. This has caused some to speculate that the first telescope was made by an Italian named Giovanni Battista della Porta. In 1589, the year that Galileo began to teach at Pisa, Porta published a book called Natural Magick in which among other things he discussed the possibilities of using two lenses: "If anyone should look through two spectacle glasses, the one being superimposed on the other, he will see everything much greater and nearer." In a later book, published in 1593, Porta said: "Old men see more clearly with convex spectacles, and those who are weak-sighted see more clearly with concave spectacles." Thus, Porta was acquainted with both convex and concave glasses and could have tried to combine them in a single instrument.

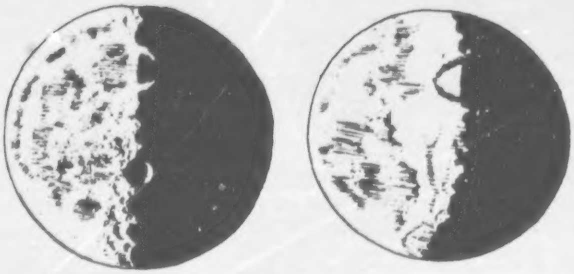
All this is mere guessing. It is interesting, perhaps, but not really worthwhile because it is neither good history nor good science. It is enough to conclude that the telescope was already in existence or a real possibility by 1600. Furthermore, the beginning of the story actually goes back three hundred years when spectacles, or eye-glasses, first began to be manufactured about 1300. In 1299, in fact, an Italian wrote: "I find myself so pressed by age that I can neither write nor read without those glasses they call spectacles, lately invented to the greater advantage of poor old men when their sight grows weak." And about ten years earlier in England another man described the magnifying glass as follows: "This instrument may be useful to old men and those who have weak eyes." And in a church in Florence, Italy, there is an inscription on a wall which reads:

HERE LIES SALVINO DEGLI ARMATI OF FLORENCE,
INVENTOR OF SPECTACLES
MAY GOD PARDON HIS SINS. MCCCXVII [1317].

The lenses of the first spectacles were most frequently made of rock crystal, but glass also began to be used. The most skillful lens grinders were those of Holland and of Venice. When Galileo was a boy, we know that the Venetians were importing glass balls from Germany which they sliced into segments and ground into lenses. In view of all this, it is not surprising that the first telescopes were to be manufactured in Holland and Venice, or that Galileo had no trouble in finding experts to grind lenses for him.

Now that we have come back to Galileo, we can approach the most important part of our story. And this concerns what he did next, for he was not satisfied to pocket the money for his telescope, but rather he began to make better ones and, most important of all, to use them for looking at the sun, moon, and stars.

What Galileo saw in the skies excited him far more than anything his telescope had shown him on the ground, for in the heavens were new worlds. Yet, the mere novelty of seeing would never satisfy a Galileo: he must find explanations for what he saw, and in order to do that he must observe and record; then once he had collected his data, he would be in a position to formulate hypotheses. At last, after several months of almost nightly observation, he was ready to explain and eager to share his discoveries with others. His first reports were published in a little book which he entitled The Starry Messenger; it appeared in Venice in 1610.

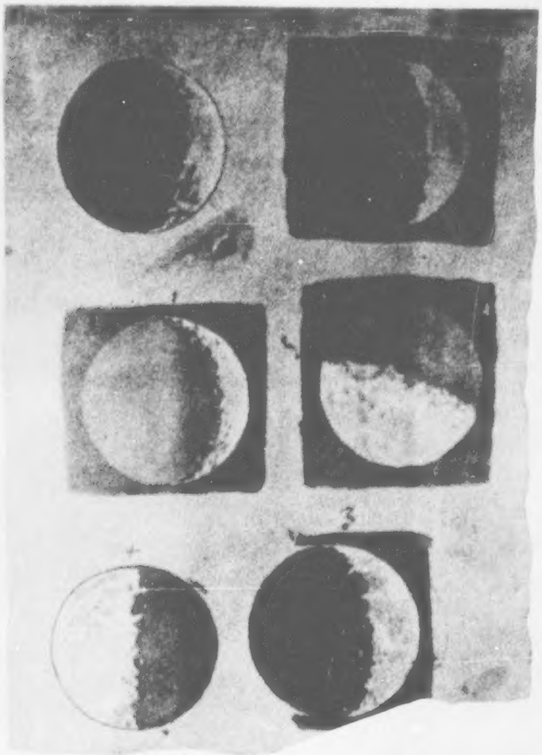


Views of the moon as drawn by Galileo

"First of all," said Galileo, "I viewed the moon." There his interest was drawn at once to what he called "moon spots." "I feel sure," he announced, "that the surface of the moon is not perfectly smooth...nor exactly spherical...but that it is uneven...full of hollows and protuberances, just like the surface of the earth itself which is varied everywhere by lofty mountains and deep valleys... I have noticed small spots that have the dark side towards the sun's position and on the side away from the sun they have brighter boundaries...Now we have an appearance quite similar on the earth about sunrise, when we behold the valleys not yet flooded with light, but the mountains surrounding them on the side opposite to the sun already ablaze with the splendour of his beams...."

As for the "great spots," as Galileo called them, which were not broken up but even and uniform, one could "revive the old opinion of the Pythagoreans [Greek philosophers], that the moon is another earth" with the brighter portion representing the "surface of the land, and the darker the expanse of water." The seas and continents of the earth, seen from the moon, would show the same appearance--so reasoned Galileo.

There was much more about the moon: he described a great crater on its surface and said that the country of Bohemia in Europe, surrounded as it was by great mountains, would look exactly like this if the observer could stand on the moon; he talked about the brightness of the moon during an eclipse when the moon could not derive its light from the sun and reasoned that this must be the earth reflecting the light of the sun upon the moon, so that the moon enjoyed earthlight just as the earth had moonlight.

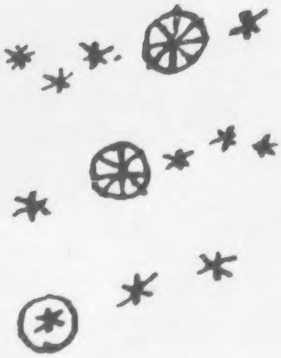


Views of the moon as drawn by Galileo

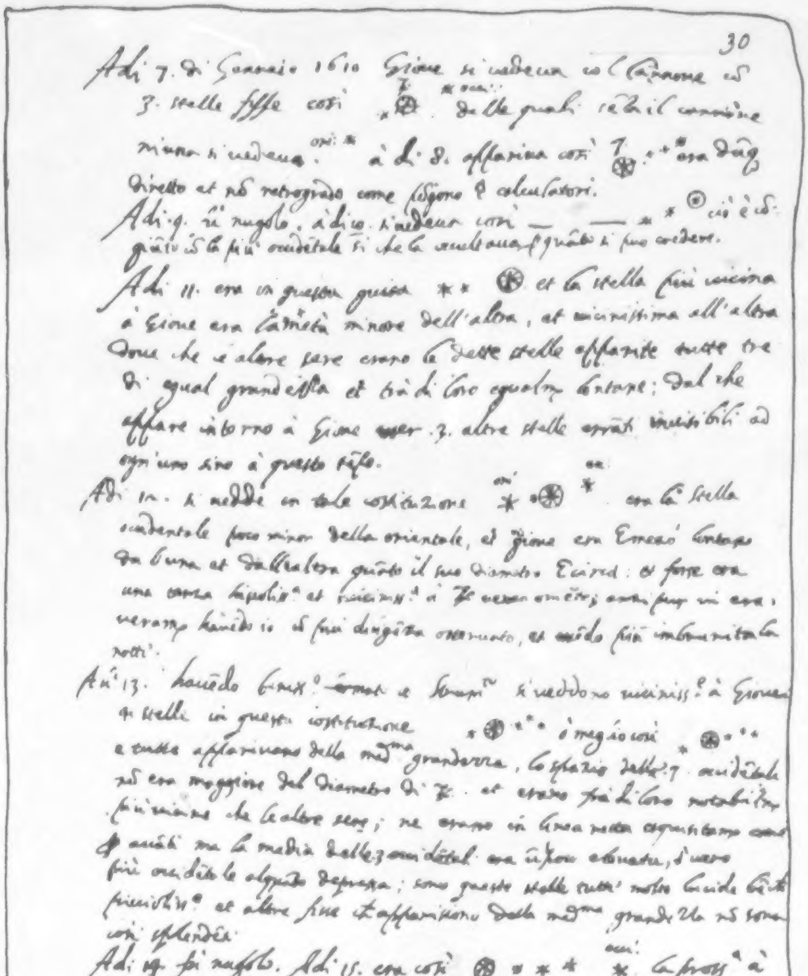
After the moon, Galileo looked at the stars and planets. Their appearance differed: "The planets present their discs perfectly round...and appear as so many little moons...but the fixed stars shoot out beams of light."

And "you will behold through the telescope a host of other stars, which escape the unassisted sight, so numerous as to be almost beyond belief.... As for the three stars in Orion's Belt and the six in his Sword, which have been long well-known groups .... I have added eighty other stars recently discovered in their vicinity .... The next object which I have observed [illegible] .... the Milky Way .... [this] Galaxy is nothing else but a mass of innumerable stars planted together in clusters."

Then came the most startling discovery of all: the four moons of Jupiter! Between January 7 and March 2, 1610, Galileo concentrated on this phenomenon, collecting the data which finally allowed him to solve the problem posed by what he had seen. On January 7 he had looked at Jupiter and noticed three "stars" almost in a straight line parallel to the equator of the planet. He took them to be new fixed stars, but on the next night when, quite by accident, he looked at Jupiter once more, he saw the three little "stars" again, this time all west of the planet whereas on the preceding night two had been on the west and one on the east. The night of January 9 was too cloudy for star-gazing, but on the 10th Galileo found that he could see only two of his three "stars," and they were east of Jupiter. The next night there were two "stars" to the east, but after a while a third appeared on the west. At last, on the 13th, Galileo saw four objects, one on the east and three on the west; by the 15th, the next night that observation was possible, all four "stars" were on the west. Further recording made it clear that these bodies were not stars, but moons or satellites revolving about the planet, and Galileo was able to establish the time required for each of the moons to complete its revolution about Jupiter: roughly speaking, the one nearest the planet took 1 day, 18 hours, and the times for the others were 3 days, 13 hours; 7 days, 4 hours; and 16 days, 16 hours.

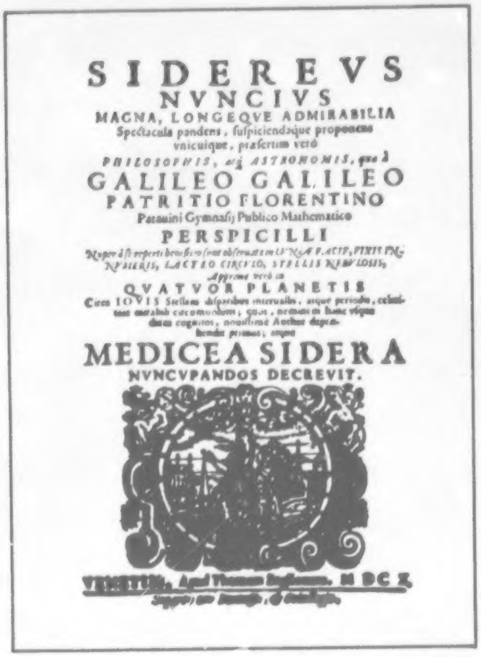


From Galileo's original drawings



Letter written by Galileo describing the discovery of the moons of Jupiter in 1610

The publication of The Starry Messenger changed Galileo's life. He had, in the most scheming way, named the four moons of Jupiter the Medicean Stars, and dedicated his book to Cosimo de' Medici, Grand Duke of Tuscany. So it came as no surprise to anyone when the Grand Duke offered Galileo a professorship at the University of Pisa and a big salary with no teaching duties. Our celebrity joined his new patron at Florence in 1610, leaving the Venetians in the lurch.

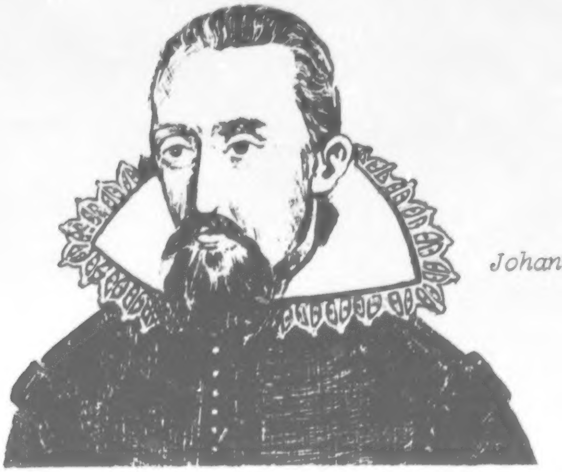


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, ſuſpiciendaque proponens
vnicuique, præſertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnaſij Publico Mathematico
PERSPICILLI
Apprime verò in
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

Title page from The Starry Messenger

The Starry Messenger also involved Galileo in a famous correspondence with the great German astronomer, Johann Kepler, and during 1610 and 1611 he wrote letters to Kepler informing him of even newer discoveries. These letters, published by Kepler at Augsburg in 1611, were interesting because Galileo used secret writing to announce what he had found. The reason for this was that Galileo was now in competition with people who were claiming to have made certain discoveries before him, and, if he announced his findings before he could get his data into print, other people might somehow undermine his priority. It did not matter that Kepler could not read the secret message; the message itself would bear a date, and Galileo could reveal the secret of his writing when he was ready to do so.

The first message to Kepler from Galileo read: smaismrmilmepoetaleumibunenugttauiras. Kepler tried rearranging the letters and thought that Galileo was telling about some discovery relating to the planet Mars, but in November 1610 a new letter from Galileo gave the message in Latin: "Altissimum planetam tergeminum observavi" -- "I have observed the most distant of planets to have a triple form." This referred to the "ring" of Saturn which Galileo thought to consist of two small bodies on either side of the main planet. Galileo was mistaken: two hundred years later



Johann Kepler

better telescopes would show that Saturn had eight moons; subsequently a ninth and possibly a tenth were seen.

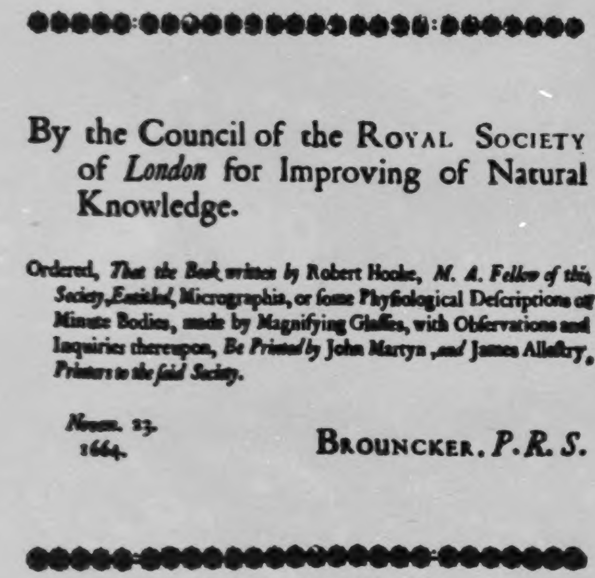
The second message came in December: "Haec immatura a me jam frustra leguntur, o.y."--"These are at present too young to be read by me, o. y." Later, when Galileo was ready, he rearranged the letters so that the sentence read: "Cynthias figuras aemulatur mater amorum"--"The mother of love imitates Cynthia's shapes," or "Venus imitates the phases of the moon," for Galileo had discovered that Venus, like the moon, might be quarter, half, or full in its appearance to the observer on earth.

Kepler called Galileo "the foremost philosopher of our day who used the telescope like a ladder to scale the highest walls of the visible world." And a Polish nobleman wrote to Galileo: "I am very glad that your name will be consecrated to immortality, and honored and admired by everyone."

Perhaps it is best that we now take leave of Galileo at the peak of his good fortune. He was to do many other things, but he had made enemies, and he had offended people who were not ready to accept his conclusions about the universe. Unhappiness lay ahead: he would become totally blind, and he would be forced to say publicly that he had been wrong in the interpretation of his data and did not believe the things that he knew secretly in his heart to be true. Old, sightless, ill, and heartbroken, he died in 1642.

LEEUWENHOEK

From the sad story of Galileo and his telescope, we may now turn to the happier one of Leeuwenhoek and the microscope. In order to do this, we can go back to our starting point of 1664 and the Micrographia of the Englishman, Robert Hooke.



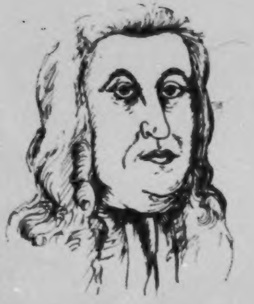
By the Council of the ROYAL SOCIETY
of *London* for Improving of Natural
Knowledge.

Ordered, *That the Book written by* Robert Hooke, *M. A. Fellow of this Society, Entituled,* Micrographia, or ſome Phyſiological Deſcriptions of Minute Bodies, made by Magnifying Glaſſes, with Obſervations and Inquiries thereupon, *Be Printed by* John Martyn *, and* James Alleſtry, *Printers to the ſaid Society.*

Novem. 23.
1664.

BROUNCKER. *P. R. S.*

Page from *Micrographia*

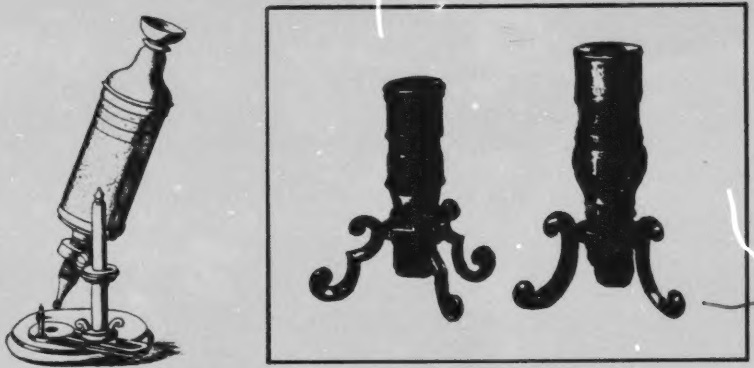


Robert Hooke

Robert Hooke's mind, like the engine in one of our modern automobiles, was almost too powerful for the body that enclosed it. It was often difficult for him to control and order the brilliant ideas that seemed to flash and dart continuously through his brain. The Micrographia, therefore, was a book about many things, but mainly it dealt with the discoveries that Hooke had made with his microscope. He described carefully the marvels he had seen and drew pictures of them as well. He looked at snowflakes, feathers, the mold on the cover of a book, the eyes and feet of a fly, the sting of a bee, and the threads of a fine linen handkerchief.

We still have his drawings, and when we try to draw the same things now as we see them through our microscopes, we appreciate what a good artist he was.

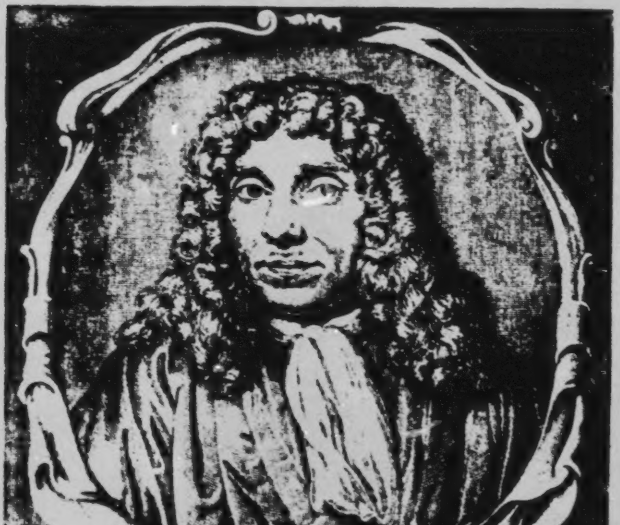
Hooke used a compound microscope, basically like the ones we have today. He was not the first man to employ this instrument (we have already seen that Janssen may have invented it in 1590), but improvements had been made that allowed Hooke to see things better than people before his time. Robert Hooke knew about some of his predecessors: Stelluti in Italy (1625), who had observed and drawn pictures of bees; Hodierna in Sicily (1648), who had studied the characteristics of human hair and looked at the tiny worms that appeared in vinegar; and several other well-known people, including Galileo.



Galileo Microscope (Right)
Robert Hooke Microscope (Left)

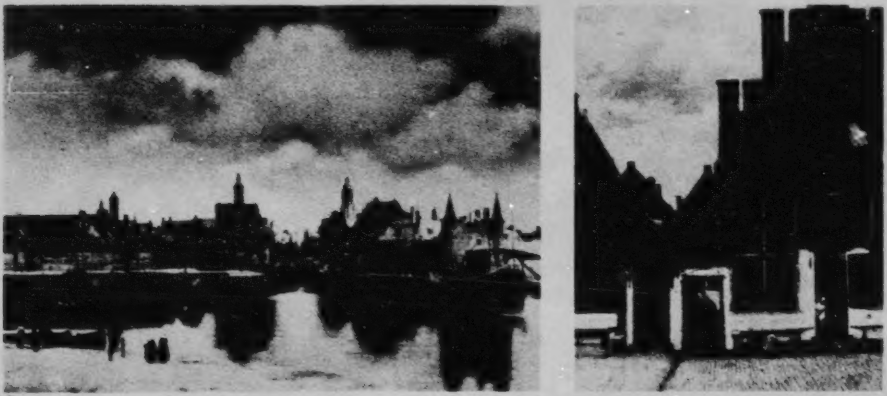
By the end of the seventeenth century, however, about thirty years after the publication of the Micrographia, Hooke came to feel that progress with the microscope was almost at a standstill. New inventions and improvements, the novelty of looking at tiny things, even research with the microscope had fallen off. The only major person still active, said Hooke, "is Mr. Leeuwenhoek, besides whom I hear of none that make any use of that instrument but for diversion and pastime, and by that reason it [the microscope] is become a portable instrument, and easy to be carried in one's pocket."

And this brings us to the subject of our second story, Antony van Leeuwenhoek, the little shopkeeper of Delft in Holland who never wrote a book and for whom the microscope was only a hobby. Yet this was the man who made the most startling discoveries of all!



ANTONIUS A LEEUWENHOEK

Leeuwenhoek was born in Delft in 1632, in the same year and in the same town as the painter, Jan Vermeer. As a child Antony did go to school, but when he was sixteen he was sent to Amsterdam to work in a linen-draper's shop and learn the business. By the age of twenty-one or twenty-two he had returned to his home town of Delft where he got married and opened a shop of his own in which he sold cloth, ribbons, buttons, and thread. This was the way he made his living for the rest of his very long life, although he did find various odd jobs to do around town. He became, for example, the Chamberlain (janitor) of the Town Hall; he was one of the city surveyors; and when Jan Vermeer died, Leeuwenhoek was appointed to administer the poor man's estate and straighten out the financial tangle the artist had left his widow.



Paintings of Delft and Leeuwenhoek's home by Jan Vermeer

Sometime, somehow, when Leeuwenhoek was in his middle thirties, he became interested in microscopes and began to make his own. Now, the microscopes of Leeuwenhoek were not compound ones like those used by Galileo and Robert Hooke. Instead, they belonged to a different variety which had appeared about 1650 and were described as follows:

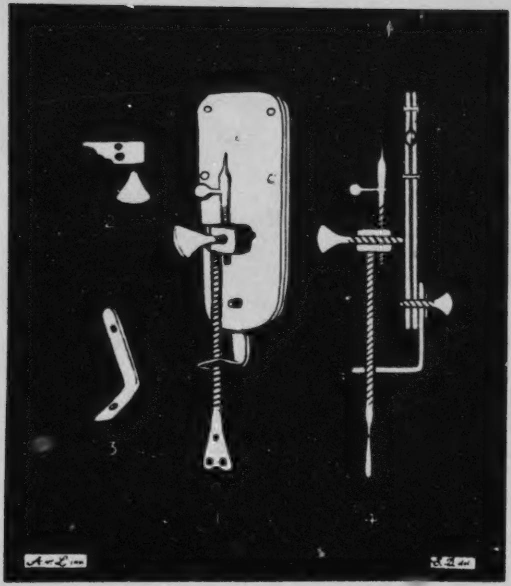
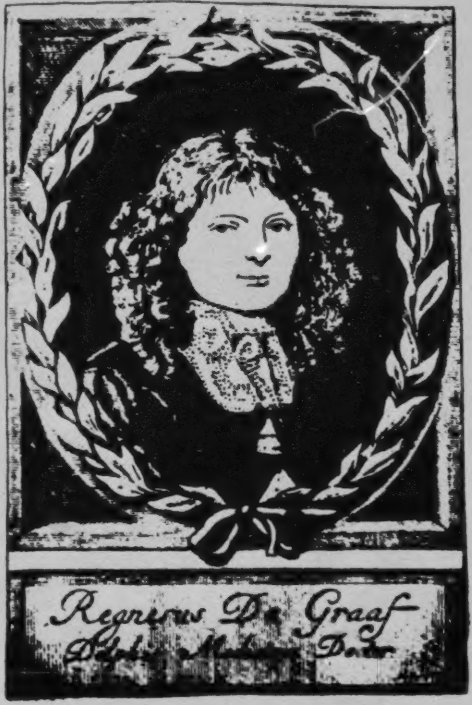


Diagram of Leeuwenhoek's microscope

"Some people insert in a certain tube very tiny glass spheres whose diameter does not exceed the diameter of very small pearls.... a novelty lately invented and for this purpose extremely well adapted: if on the surface [of the sphere] you apply the foot of a flea between the eye and a lamp you will see a thing marvelous to behold, its upper leg in the grim likeness of a horse's foot: but the hair thereon will remind you of an immense beam...."

Leeuwenhoek's microscopes were really tiny magnifying glasses. The lenses were ground glass or crystal, generally smaller than the little bulb-ends found in our penlight flashlights (which also can be used for high magnification). Leeuwenhoek's lenses were not spheres; they were double convex glasses, and each little lens was mounted between two brass plates. The object to be viewed was placed on the tip of a small metal pin. The pin itself was attached to the metal plates, and its position could be adjusted so that the object was brought into focus before the lens. In Hooke's microscopes, of course, one adjusted the focus by moving one of the lenses while the object remained stationary, while Leeuwenhoek's glass remained always in the same position, and the observer instead adjusted the object until it was clearly and sharply in view. The magnification possible with Leeuwenhoek's marvelously ground lenses was amazing: their capability ranged all the way from 50 to 200 diameters.

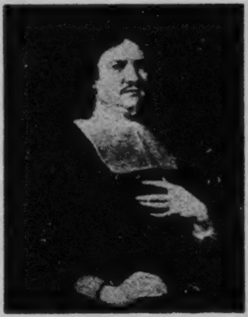
For a few years Leeuwenhoek's new hobby was known only to a handful of his fellow townsmen. One of these, however, was a person of some importance, a doctor named Regnerus (or Renier) de Graaf. De Graaf, unlike the other villagers, was in contact with



the outside world; on occasion, he had corresponded with the members of the Royal Society of London, the same group which had sponsored the publication of Hooke's Micrographia.

The Royal Society of London was one of the three important organizations for the promotion of scientific research which were founded in the seventeenth century. The other two were the Academy of Experiments established in Florence, Italy, in 1657 and the Paris Academy of Science founded in 1666. The Royal Society of London was chartered by King Charles II of England in 1662.

In all three cases the formation of the society had been preceded by informal meetings of people interested in or working in mathematics and science. In Florence, for example, several persons who were pupils of Galileo were mainly responsible for the organization and financial support of the Academy of Experiments. In England, two groups -- one in London and the other at Oxford University -- had been meeting periodically for several years before the Royal Society was given a formal charter and government support.



Henry Oldenburg, The Royal Society of London

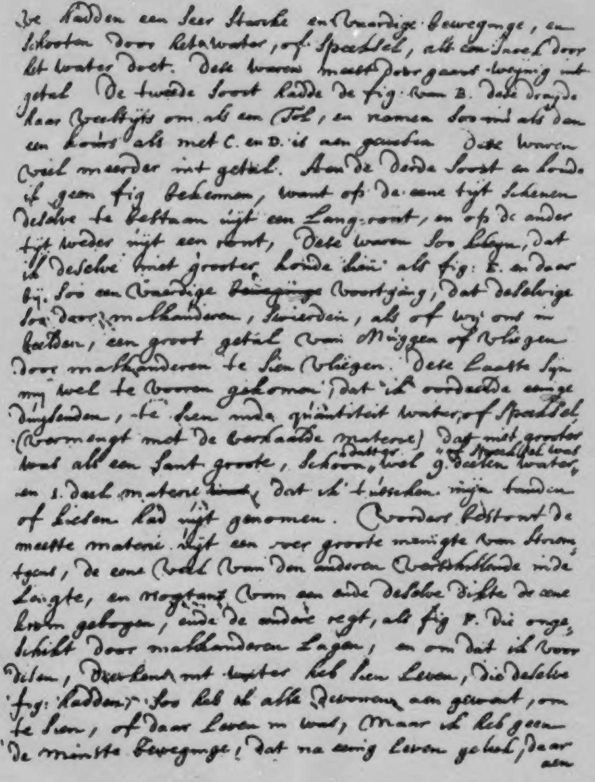
The Royal Society met three or four times a month to witness experiments in physics and chemistry and to watch demonstrations of new scientific equipment. Members also read papers on subjects in which they were interested. Many of the experiments were set up for demonstration by Robert Hooke, who was employed for this purpose by the Society. Henry Oldenburg, President of the Royal Society for many years, soon began to publish papers on mathematics, astronomy, and various related subjects in the volumes of the Philosophical Transactions of the Royal Society. The papers were written by members, but letters from foreign correspondents (like Leeuwenhoek) were included.

Despite the wars which England waged against European powers during this period, Oldenburg kept up his correspondence with people in enemy territory who were interested in science and who had news to communicate or wished to keep abreast of scientific developments. Oldenburg got so much foreign mail that people began to think him a traitor. To avoid suspicion he had to ask his correspondents to send their letters to other addresses and not to put his name on their envelopes; but, for example, a letter sent to "Mr. Grubendol" in London would eventually find its way to Henry Oldenburg. At one point poor Henry was arrested and imprisoned in the Tower of London as a spy, but he was soon released.

To get back to our story, Oldenburg was not only the Secretary of the Royal Society, but he was also the editor of its publications, and when he published a report about an Italian named Divini who had made extraordinary lenses that "showed a creature smaller than anyone had ever seen before," patriotism moved Dr. de Graaf of Delft to write to Henry Oldenburg of London.

"I am writing," he said, "to tell you that a certain most ingenious person here, named Leeuwenhoek, has devised microscopes which far surpass those ..... manufactured by E[illegible]chio Divini and others. The enclosed letter from him ..... will afford you a sample of his work ...."

This was 1673. Leeuwenhoek's first letter was not a very impressive one. He described mold and the sting and other parts of a bee, things which Robert Hooke had already written about years before. Nevertheless, the Royal Society was kind and encouraged Leeuwen-



Sy hadden een seer sterke en vaerdige beweginge, en
schooten door het water, of speeksel, als een snoek door
het water doet. Dese waren meest door gaans weynig in
getal. De tweede soort hadde de fig: van B. dese drayde
haar veeltijts om als een Tol, en namen soo nu als dan
een koers als met C. en D. is aen gewesen. Dese waren
veel meerder in getal. Aan de derde soort en konde
ik geen fig bekomen, want op de eene tijt scheenen
deselve te hebben uyt een Lang-ront, en op de ander
tijt weder uyt een ront, Dese waren soo kleyn, dat
ik deselve niet grooter konde sien als fig: E. en daar
bij, soo een vaerdige ~~beweginge~~ voortgang, dat deselvige
soo door malkanderen swierden, als of wij ons in
beelden, een groot getal van Muggen of vliegen
door malkanderen te sien vliegen. Dese laatste sijn
mij wel te vooren gekomen, dat ik oordeelde eenige
duysenden, te sien in een quantiteit water, of speeksel,
(vermengt met de verhaalde materie) dat niet grooter
was als een sant groote, schoon, datter wel 9. deelen water, of speeksel was
en 1. deel materie, dat ik tusschen mijn tanden
of kiesen had uyt genomen. Voorder bestont de
meeste materie uyt een seer groote menigte van Strom
tgens, de eene veel van den anderen verschillende in de
Langte, en nogtans van een ende deselve dikte, de eene
krom gebogen, ende de andere regt, als fig F. die onge-
schikt door malkanderen lagen, en om dat ik voor
desen, dierlijke met water heb sien Leven, die deselve
fig: hadden; soo heb ik alle devoiren aen gewent, om
te sien, of daar leven in was, Maar ik heb geen
de minste bewegingen, dat na eenig leven geleek, daar
aen

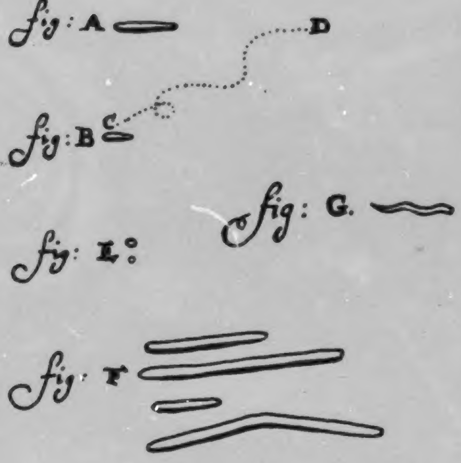
Letter written by Leeuwenhoek to the Royal Society describing his discoveries

hoek to write other letters. And for the next fifty years, he did write letter after letter. As his skill in making lenses and his powers of observation improved, the Royal Society was richly rewarded for its kindness, as we shall presently see.

Since Leeuwenhoek knew only Dutch, his letters for the Royal Society had to be translated into English. Later on, he got a friend to translate his letters into Latin, a language which most educated people in England, France, Germany, Italy, and other European countries could read. With the translation and publication of his letters, Leeuwenhoek's fame spread. People came to Delft to visit him and to look through his microscopes. Not all the visitors were scientists or curious travelers; a Queen of England came, and on one occasion, Peter the Great, Tsar of Russia, made a special side-trip to Delft as he was touring western Europe. Fame brought honors, too. At the urging of Robert Hooke and others, Leeuwenhoek was elected a member of the Royal Society, and a certificate of membership with the seal of the Royal Society attached was sent to the new member in a handsome silver box.

Why was Leeuwenhoek so famous? Because with his microscopes he saw and described for the first time living organisms that no other person had ever seen or even imagined existed. He saw bacteria, for example, and he was the first to see single-celled creatures, protozoa. Leeuwenhoek did not know, nor did anyone else for a long time afterward, the true identity or function of these organisms. For him, they were all animalcules, his "little animals."

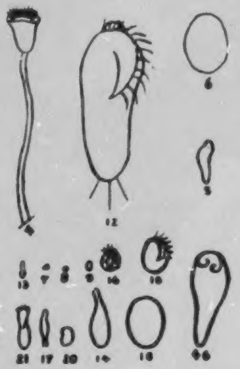
Leeuwenhoek first saw his "little animals" in 1675. He observed them over a period of a year and kept a



Drawing of Bacteria from the Human Mouth by Leeuwenhoek diary of his observations. Then finally on October 9, 1676, he wrote a very long letter to the Royal Society: "In the year 1675 about mid-September....I discovered living creatures in rain water which had stood for a few days in a new painted cask. This invited me to view this water with great attention, especially those little animals appearing to me ten thousand times smaller than those....called water fleas....which may be seen with the naked eye."

The little animals were not all alike. Leeuwenhoek could see at least five different kinds, and he described them as best he could. One variety, he said, moved by putting out two little horns like horses' ears -- "they were the most wretched ones I ever saw." They wound their tails around little threads of matter in the water, and, when they managed to free themselves again, they rolled up like copper wire that had been wound about a stick.

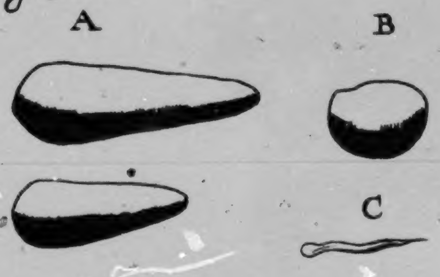
Using the notes he had jotted down in his diary, Leeuwenhoek described a series of observations and tests which he had made between May and September of 1676. On May 26 it rained hard. He caught rain water as it poured off the roof and found little animals in the water. These might, he thought, have come from the gutter, so he put out in his courtyard a clean porcelain dish and let the rain fall directly from the sky into it. This time he saw no little animals at all until about four days had passed. Then his dish teemed with little creatures, a million of which, he said, would not be as big as a grain of sand. He repeated the test with the rain water caught directly from the sky and got the same results. Then he put a glass of rain water in his study, carefully shielded from sun and air. With more precise observation, he found that the little animals began to appear after 24 hours.



Micro-organisms drawn by Leeuwenhoek

As time passed, and further experiments were made, Leeuwenhoek found nearly twenty different kinds of creatures: very small ones that swam gently "among one another, moving like gnats do in the air; bigger ones moving far more swiftly, tumbling around as it were, and then making a sudden downfall." He found his little animals in canal water, well water, and sea water. The last he got by giving a glass bottle to a man "that went to the sea to wash himself." It was in the sea water that Leeuwenhoek found single-celled animals, the protozoa. We know this from his description: "Although they were a thousand times smaller than a grain of sand, yet I discerned, that when they lay out of the water in a dry place, they burst in pieces and spread into three or four little globules...."

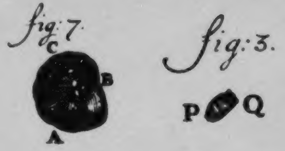
fig:3



Drawing of the Intestinal Protozoa of Frogs by Leeuwenhoek.

Not content with rain, canal, well, or sea water, Leeuwenhoek next put pepper in rain water and also in well water, and then he tried vinegar and water. Strong solutions of pepper or vinegar, he found, would kill the little animals, but after the mixture had stood for a while, new creatures would appear in it. In the pepper water Leeuwenhoek first encountered bacteria, though he did not know what a revolutionary discovery he had made. For him the bacteria were simply another kind of creature, so incredibly small that one hundred of them laid end to end would not equal the length of a coarse grain of sand.

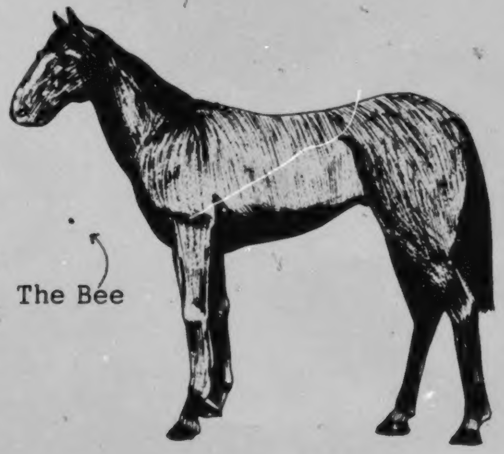
How could one measure or count these little animals? One might compare them with a grain of sand or with each other. Leeuwenhoek tried to measure and to count, and he had his friends look through the microscope, but the observers rarely agreed among themselves. So it seemed that the microscope, that new instrument, had created a need for other instruments. Galileo had experienced the same difficulty in trying to measure the radii of the orbits of Jupiter's moons. What both needed was a micrometer for more careful adjustment: such an instrument was provided for the telescope in 1667, long after Galileo's death, while Leeuwenhoek had also died before a micrometer for microscopic bodies was devised. As a result, Leeuwenhoek could rely only on rough comparisons, and thus he wrote to Constantine Huygens, father of the great scientist, Christiaan:



Two of Leeuwenhoek's figures enlarged from original engravings

Gelijck een kleijn diertge int water
Tot de grootheijt een miter
Alsoo een Honich bije
Tot de groote van een paart.

[As a little animal in the water
Is to a mite
So a honey-bee
Is to a horse.]

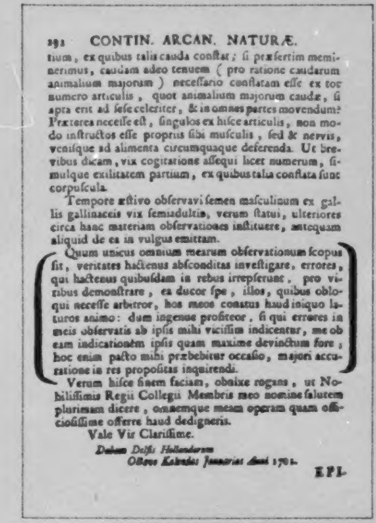


Incidentally, the Royal Society, with the proper scientific spirit, was not inclined to accept Leeuwenhoek's findings without some tests of its own. On November 8, 1677, Robert Hooke prepared a demonstration using pepper water and his own microscopes, but no little animals could be seen. One member scoffed that Leeuwenhoek had not seen anything but little particles of pepper in the water. Nevertheless, Hooke was instructed to make another test, and a week later there was success at last: "By all who saw them, they were verily believed to be animals....They were seen by Mr. Henshaw, Sir Christopher Wren....and others; so that there was no longer any doubt of Mr. Leeuwenhoek's discovery."

Quite aside from his skill as an instrument maker and his great powers of observation, Leeuwenhoek had the common sense, caution, and modesty essential for scientific research. He was open-minded, willing to accept criticism and to admit his mistakes. He once said: "I aim at nothing but truth!"

More than this, Leeuwenhoek seemed to have a natural feeling for scientific method. We have seen how he tested with endless patience various kinds of water and mixtures in his search for his little animals. We have also seen how he kept up his investigations over a period of days and weeks and carefully recorded his observations -- just as Galileo had done with the moons of Jupiter. Even better, Leeuwenhoek did not rush to put forward a theory on slight evidence, but considered all the possible explanations that he could think of until he was able to throw out some and confirm others.

We should not be surprised that Leeuwenhoek failed to arrive at conclusions that seem simple and clear enough to us now. He was, for example, very proud of his teeth which remained in fine condition even into



tium, ex quibus talis cauda conſtat; ſi præſertim meminerimus, caudam adeo tenuem (pro ratione caudarum animalium majorum) neceſſario conflatam eſſe ex tot numero articulis, quot animalium majorum caudæ, ſi apta erit ad ſeſe celeriter, & in omnes partes movendum? Præterea neceſſe eſt, ſingulos ex hiſce articulis, non modo inſtructos eſſe propriis ſibi muſculis, ſed & nervis, veniſque ad alimenta circumquaque deferenda. Ut brevibus dicam, vix cogitatione aſſequi licet numerum, ſimulque exilitatem partium, ex quibus talia conflata ſunt corpuſcula.

Tempore æſtivo obſervavi ſemen maſculinum ex gallis gallinaceis vix ſemiadultis, verum ſtatui, ulteriores circa hanc materiam obſervationes inſtituere, antequam aliquid de ea in vulgus emittam.

Quum unicus omnium mearum obſervationum ſcopus ſit, veritates hactenus abſconditas inveſtigare, errores, qui hactenus quibuſdam in rebus irrepſerunt, pro viribus demonſtrare, ea ducor ſpe, illos, quibus obloqui neceſſe arbitror, hos meos conatus haud iniquo laturos animo: dum ingenue profiteor, ſi qui errores in meis obſervatis ab ipſis mihi viciſſim indicentur, me ob eam indicationem ipſis quam maxime devinctum fore; hoc enim pacto mihi præbebitur occaſio, majori accuratione in res propoſitas inquirendi.

Verum hiſce finem faciam, obnixe rogans, ut Nobiliſſimis Regii Collegii Membris meo nomine ſalutem plurimam dicere, omnemque meam operam quam officioſiſſime offerre haud dedigneris.

Vale Vir Clariſſime.

Dabam Delphis Hollandorum
Octavo Kalendas Januarias Anni 1701.

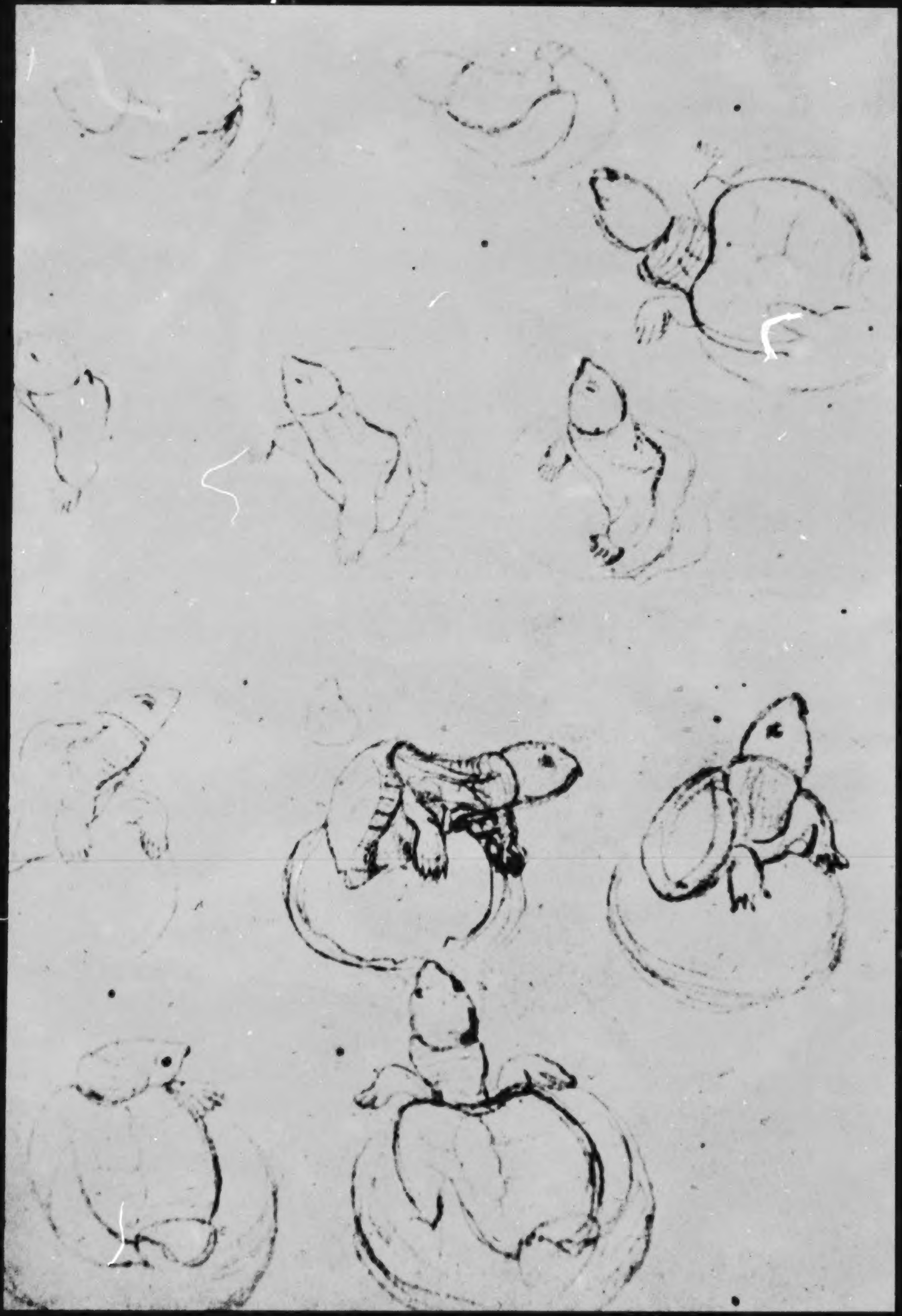
EPI-

Leeuwenhoek's letter in Latin (left) to the Royal Society is translated in part into English below:

"Since I aim at nothing but truth and as best I can to show the errors that have crept into certain matters; I hope that in doing this that those whom I perceive it necessary to contradict will by no means consider it unfair; and frankly if they would indicate to me any errors in my own observations, I should be grateful; particularly because this would provide an opportunity for me to achieve greater accuracy in research."

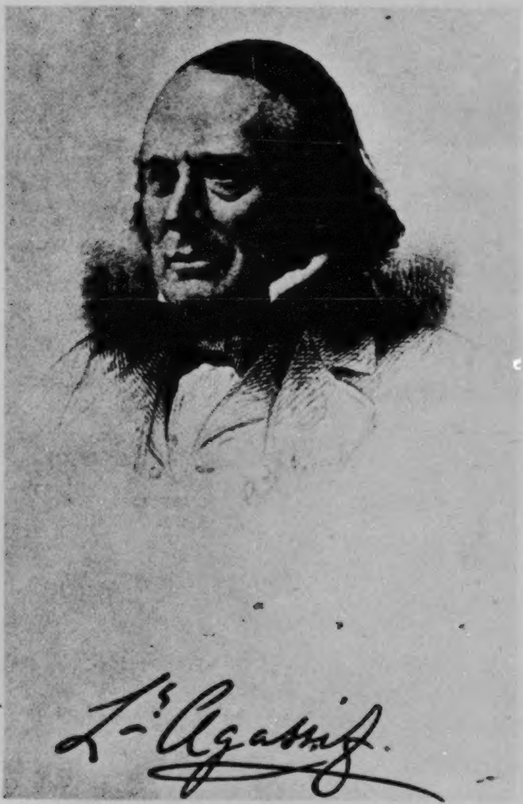
his old age. He tells us that he scrubbed his teeth with salt every day and dislodged food particles with a toothpick, yet he discovered "white material" between his teeth that contained the little animals. If he put vinegar in his mouth, most of the little animals died as they did also after he drank his hot morning coffee, yet it does not seem to have occurred to him that there might be some connection between his little animals on the one hand and disease and decay on the other. Some people of his day did speculate about this, but it was another hundred and fifty years before Louis Pasteur firmly took this question in hand.

As his tombstone relates, our grand old man lived on (1723) to the ripe age of "90 years, 10 months, and 2 days." He continued to write letters to the very end, and the Royal Society did not overstate the case when it admitted that "we have lost a worthy member and a most valuable correspondent."



LOUIS AGASSIZ

THE PIED PIPER OF SCIENCE



Agassiz in 1855

LOUIS AGASSIZ, THE PIED PIPER OF SCIENCE

"What is your greatest work?"

"I have taught men to observe."

These were the words of a great teacher, a world-famous scientist who came to America on a visit more than one hundred years ago and unexpectedly stayed on to make this country his classroom and the New World his laboratory.

The name of this man was Louis Agassiz. Born in Switzerland in 1807, he got his university education in Germany. By the age of twenty-three he had earned a Ph.D., published a learned book, and qualified as a doctor of medicine. Within another fifteen years Agassiz was known everywhere as an authority on natural history. By then the author of more than twenty books, he had written about fossil fish as well as about the modern fishes of Brazil and Central Europe, while his original and on-the-spot studies of European glaciers had established beyond a doubt that the Old World had once suffered an Ice Age when the great frozen sheets of the glaciers had covered parts of western Europe.

In 1846, when Agassiz came to the United States, there was neither radio nor television, so people got most of their information from reading books, magazines, and newspapers, but they also flocked in great numbers to hear public lectures on a variety of subjects. Many of these lectures were given by some very famous persons. Rich and poor, merchants and shopkeepers, industrialists and factory workers crowded into the lecture halls, eager to learn. Five thousand people came to hear Agassiz when he spoke at the Lowell Institute in Boston. Delighted by the interest and enthusiasm shown by his audiences not only in Boston but also in other cities, Agassiz began to consider a longer stay in the United States. Then, when the revolutions of 1848 swept across Europe and he was offered a professorship at Harvard, the great scientist decided not to go home. For the next twenty-five years until his death in 1873, Agassiz studied the creatures of the New

World, taught young men to do competent research in natural history, and helped to organize scientific studies in the United States.

Agassiz in 1861

A magnificent speaker with a personality that charmed men, women, and children alike, he expressed himself so simply and clearly that he was equally effective in talking to professors, schoolteachers, or the pupils in the elementary grades. This, for example, is what Agassiz once said about comparison and classification:

"Suppose we see together a Dog, a Cat, a Bear, a Horse, a Cow, and a Deer. The first feature that strikes us as common to any two of them is the horn in the Cow and Deer. But how shall we associate either of the others with these? We examine the teeth, and find those of the Dog, the Cat, and the Bear sharp and cutting, while those of the Cow, the Deer, and the Horse have flat surfaces, adapted to grinding and chewing, rather than cutting and tearing.

We compare these features of their structure with the habits of these animals, and find that the first are carnivorous, that they seize and tear their prey, while the others are herbivorous or grazing animals, living only on vegetable substances, which they chew and grind. We compare further the Horse and Cow, and find that the Horse has front teeth both in the upper and lower jaw, while the Cow has them only in the lower; and going still further, and comparing the internal with the external features, we find this arrangement of the teeth in direct relation to the different structure of the two animals – the Cow having a stomach with four pouches, adapted to a mode of digestion by which the food is prepared for the second mastication, while the Horse has a simple stomach. Comparing the Cow and the Deer, we find that the digestive apparatus is the same in both; but though they both have horns, in the Cow the horn is hollow, and remains through life firmly attached to the bone, while in the Deer it is solid and shed every year. With these facts before us, we cannot hesitate to place the Dog, the Cat, and the Bear in one division, as carnivorous animals, and the other three in another division as herbivorous animals – and looking a little further, we perceive, that, in common with the Cow and the Deer, the Goat and the Sheep have cloven feet, and that they are all ruminants, while the Horse has a single hoof, does not ruminate, and must therefore be separated from them, even though, like them, he is herbivorous."

"Read nature, not books," was Agassiz's advice to his students, and when a young man came to study with him, he

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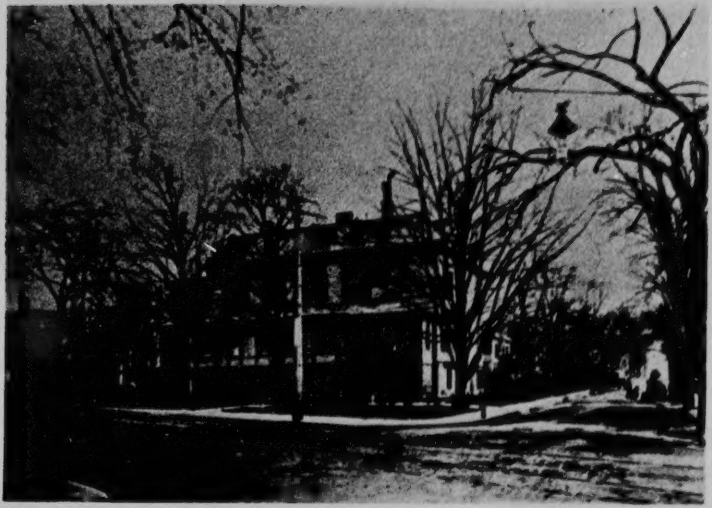
was usually made to begin with what Agassiz called the First Lesson — "Looking."

On one occasion a beginning student was assigned a small pine table with a rusty tin pan upon it. Agassiz brought the young man a small fish which had been preserved in alcohol and told him to study it. He was forbidden to talk to anyone about the fish, read anything about fishes, or use a magnifying glass; neither could he dissect or damage the specimen in any way.

"When I think you have done the work," said Agassiz, "I will question you."

Agassiz in his study



The Agassiz home, Quincey Street, Cambridge

The student recalled his experience in the following words:

"In the course of an hour I thought I had compassed that fish; it was a rather unsavory object, giving forth the stench of old alcohol, then loathsome to me, though in time I came to like it. Many of the scales were loosened so that they fell off. It appeared to me to be a case for a summary report, which I was anxious to make and get on to the next stage of the business. But Agassiz, though always within call, concerned himself no further with me that day, nor the next, nor for a week. At first this neglect was distressing; but I saw that it was a game, for he was . . . (secretly) . . . watching me. So I set my wits to work upon the thing, and in the course of a hundred hours or so I thought I had done much – a hundred times as much as seemed possible at the start. I got interested in finding out how the scales went in series, their shape, the form and placement of the teeth, etc. . . . . At length, on the seventh day, came the question, 'Well?' and my disgorge of learning to him as he sat on the edge of my table puffing his cigar. At the end of an hour's telling, he swung off and away, saying: 'That is not right.'"

"I went at the task anew, discarded my first notes, and in another week . . . I had results which astonished myself and satisfied him. Still there was no trace of praise in words or manner. He signified that it would do by placing before me about a half a peck of bones, telling me to see what I could make of them. . . . I soon found that they were skeletons of a half dozen fishes of different species. . . . The task was evidently to fit the separate bones together in their proper order. I shall never forget the sense of power in dealing with things which I felt in beginning the more extended work on a group of animals. I had learned the art of comparing objects, which is the basis of the naturalist's work."

Later, the same student was studying two groups of fishes which were supposed to differ in that each group had a distinct type of scales. Since this classification had been made by Agassiz, the student was delighted when he found that one species of his fish had one type of scales on one side of his body and the second type on the other side. He had caught the great Agassiz in error! Running to Agassiz to report his discovery and to enjoy his revenge, the student was crushed when Agassiz merely smiled and said:

"My boy, there are now two of us who know that."

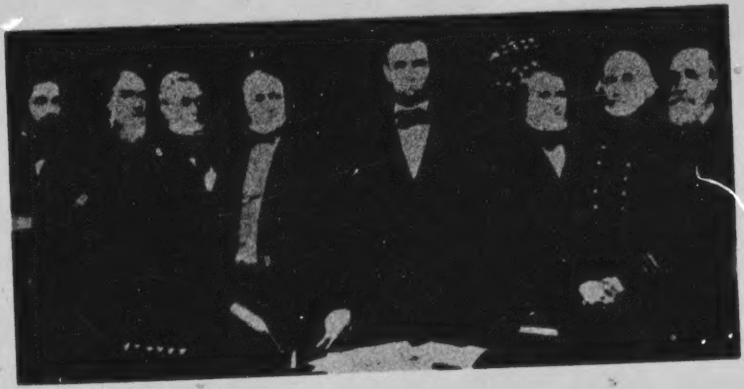
But this was the end of Lesson One, and in the future Agassiz devoted much time to the student who had proved himself. Eventually, the young man became a well-known scientist in his own right.

After coming to the United States Agassiz was to travel widely in order to see the country and its creatures at first hand. He explored the region of Lake Superior, went on a mission to Florida, and led a party of students to Brazil. One of his achievements was to establish a great museum of comparative zoology at Harvard. Agassiz had many distinguished friends; among them were Henry Wadsworth Longfellow, Ralph Waldo Emerson, and Nathaniel Hawthorne.

Emerson

Longfellow

Below is a picture of a famous painting which shows Agassiz with President Abraham Lincoln and important scientific leaders as they founded the National Academy of Sciences.



Agassiz's drawings of turtles

Agassiz was a colorful, lively person about whom many stories were told. One of these had to do with his great study of the embryology of the turtle which traced the development of turtles from the time the eggs were laid until the fully developed turtle burst from his shell. The work nearly completed, Agassiz had been able to observe every stage of the process except the very beginning — the appearance of the interior of the eggs when they had just been laid. In order to do this he must have eggs that were less than three hours old. It was not going to be easy to find such eggs in the vicinity of Cambridge or Boston, and so Agassiz got the assistance of a young schoolteacher named Jenks who lived in a town about forty miles away.

The story of this adventure is a famous one. Called "Turtle Eggs for Agassiz," it was first published by Dallas Lore Sharp in 1912. A short, modernized version for younger readers is given here:

When I was younger, I was the principal of an academy, or high school. One day, when I was busy with a class, a large man suddenly appeared in the doorway of our room, smiled at all of us, and called out with a big, quick voice that he was Professor Agassiz.

Of course he was. I knew it, even before he had time to shout it to me across the room.

Would I get him some turtle eggs?

Yes, I would.

And would I get them to Cambridge within three hours from the time they were laid?

Yes, I would. And I did. And it was worth doing. But I did it only once!

When I promised Agassiz those eggs I knew where I was going to get them. I had gotten turtle eggs there before — from a patch of sand by a pond not far from the academy.

Three hours was the limit. It was thirty-five miles from the railroad station to Boston. From the pond to the station was three or four miles, and it was another three miles from Boston to Cambridge. We figured it all out and got the trip down to two hours: driving from the pond to the station; from the station by fast train to Boston; from Boston to Cambridge by carriage. This left an easy hour for accidents and delays.

It was all included in our time-table – all except the turtle. Let me warn you that when you go after turtle eggs, don't forget the turtle!

It was early spring when Agassiz came to the academy, long before the turtles would be laying. But I was eager and so afraid of failure that I began to watch at the pond at least two weeks before the time when the turtles might be expected to lay. I remember the date: it was May 14.

A little before dawn – about three o'clock – I would drive to the pond, hitch my horse near by, hide in the cedars by the sand where I could see the whole sleeping pond, eat my breakfast, and watch for turtles until it was time to return to the academy for morning classes.

I soon came to know every one of the dozen turtles that lived on my side of the pond. When the cold morning mist lifted, they would stick up their heads through the quiet water, and when the sun rose over the ragged rim of the tree tops they would float into the warm, lighted spots, or crawl out to sleep on tufts of grass or logs.

What mornings those were! How fresh and new! The odors of the woods, the pond, the ploughed fields, water lilies, and wild grapes! I can taste them yet, and hear the sounds of the waking day – the stir of feet and wings among the trees.

Those were rare mornings, but there began to be a good many of them, for the turtles showed no desire to lay. They slept in the sun, and never one came out upon the sand as if she intended to help on the great professor's book.

June first found me still among the cedars, still waiting, as I had waited every morning, Sundays and rainy days alike. June first saw a perfect morning, but every turtle slid out upon her log, as if egg laying might be a matter for next year rather than this one.

I watched on to the end of the first week, then the second week in June. A month of morning mists wrapping around me had at last soaked through to my bones. The excitement, the fun of it, had given way to a chilling misery.

Then came a mid-June Sunday morning, with dawn breaking a little after three: a warm wide-awake dawn, with the level mist lifting from the pond a full hour earlier than I had seen it any morning before.

This was the day. I knew it! I have heard people say that they can hear the grass grow, or that they know by some extra sense when danger is near. I believe this. For a month I had been watching, and now I knew that this was the day!

Leaving my horse unhitched, as if he too understood, I slipped eagerly into the cedars for a look at the pond. A great fish ploughed a furrow through its quiet waters, and behind him rose the head of an enormous turtle. Swinging slowly around, she headed straight for the shore, and without a pause scrambled out on the sand.

As big as the scoop of a large shovel, on she came, shuffling over the sand towards the open fields. She paddled up a narrow cow path into the high grass along a fence. And up the path, on all fours, just like another turtle, I paddled after her. Under the fence she squeezed into a wild, wet pasture, full of briers and berry vines. Still on all fours, carrying in my teeth the pail of sand in which I intended to put my turtle eggs, I followed the old she-monster becoming more scratched and soaked with every movement. Then she turned and crossed a dusty public road, shuffling into a field of young corn where she began to paw about between the rows in the soft loose soil. She tried this place, and that place, and the other place. Would she never find *the* place? Then at last she found it, backed into it, and, tail first, began to bury herself before my staring eyes.

Minutes became hours long. There she was, her shell just showing. How long would she stay there? How would I know if she had laid an egg?

I could still wait. And so I waited until over the freshly awakened fields floated four mellow strokes from the distant town clock.

Four o'clock! There was no train until seven! In three hours the eggs would spoil! Then I realized that this was Sunday morning, and there was no seven o'clock train – none till after nine.

What could I do? Just then the turtle began to crawl away. There in the dirt were the eggs. What of Agassiz and his great book? He must have them, trains or no. The eggs would go to Agassiz by seven o'clock, if my horse must gallop every mile of the way. Forty miles! Any horse could cover it in three hours – if he had to.

Upsetting the surprised turtle, I scooped her round eggs from the dust. In my pail of sand I laid them, carefully covered with more sand, and then I ran for my horse.

That horse knew, as well as I, that the turtle had laid, and that he must get those eggs to Agassiz. He turned out of the field and into the road on two wheels, a thing he hadn't done for twenty years, throwing me to the floor of the buggy doubled up in front of the dashboard with the pail of eggs lodged between my knees. I let him go. If only he could keep this pace all the way to Cambridge! I shouted him on, holding to the dashboard with one hand and my pail of eggs with the other, not daring to get off my knees. Nothing must happen to the eggs. They must not be jarred or turned over before they came to Agassiz.

In order to get out on the main road it was necessary to drive back away from Boston toward the town. We had nearly covered this distance, when ahead of me, toward the railroad station, I heard the whistle of a locomotive.

What train was this? Where was it going? I pulled into a side road that ran beside the track and presently saw, perhaps a mile away, a freight train just leaving the station and heading in the direction of Boston. With little time to spare, I drove my horse through a level field and up on the railroad track in the path of the approaching train. That train should carry me and my eggs to Boston!

The engineer saw me standing up in the buggy. He saw my hat blow off, saw me wave my arms, saw the tin pail swinging in my teeth. He blew a series of sharp blasts on his whistle, and then in desperation brought his train to a halt. I backed my horse off the rails, jumped from the buggy, ran down the track, and leaped into the cab of the engine before the engineer and his fireman could move to stop me. Perhaps they didn't dare, for I looked strange, not to say dangerous. Wet, hatless, smeared with yellow mud, and holding – as if it were a bomb – a little tin pail of sand.

"Throw her wide open," I commanded. "These are turtle eggs for Professor Agassiz. He must have them before breakfast."

They knew I was crazy then. Thinking it best to humor me, the engineer opened the throttle wide and away we went.

I kissed my hand to my horse, now grazing in the open field, and smiled at the train crew. That was the best I could manage while holding myself and the eggs together. The trainmen smiled at me, though one of them held fast to his big shovel, while the other kept his hand near a large ugly wrench. Neither spoke to me, but I heard enough of what they were saying to each other to understand that they were rushing to Boston to hand me over to the police.

Station after station whizzed past until in the distance we could see the great dome of the Boston State House. It would never do to remain in the engine cab until we reached the terminal. I was clearly an escaped lunatic who had held up a train. If turned over to the police, I could never explain my case in time to get the eggs to Agassiz.

I had not thought of my appearance much before. Here I was, face and clothes caked with yellow dirt, my hat gone, my hair wild and matted, and in my hands a tiny pail of sand, as if I had been digging all night with a child's tin shovel on the beach. This was no way to appear in the streets of Boston on a Sunday morning!

As I began to feel like a hunted criminal, the train slowed down in the outer freight yards and came to a stop. I was ready to jump, but I had no chance. I looked at my watch. It was only six o'clock, with a whole hour to get to Cambridge.

Five minutes, ten minutes, went by. We were moving again, slowly into a siding. As the fireman leaned forward to grasp the bell rope, my opportunity came. I leaped from the train and ran for the fence that separated the train yard from the adjoining street.

I was ready to climb over the high boards when it occurred to me that I might drop right down into a policeman's arms. Hanging my pail on the top of a post, I peered cautiously over the barrier. Sure enough, in the open square toward the station was a great burly policeman swinging his club. He must be looking for me! Then back in the train yard some one shouted, and there was nothing left to do but slide over the fence. Fortunately, the policeman had moved on out of sight while there by the station now stood a carriage.

The driver saw me coming. I waved a dollar at him, then another, and jumped into his carriage, calling "Cambridge!"

He would have taken me straight to the police if I hadn't said, "Harvard College. Professor Agassiz's house. I've got eggs for Agassiz."

I gave him another dollar. It was nearly half past six.

"And here's another dollar," I said, "if you make Agassiz's house in twenty minutes. Never mind the police."

Whirling around a corner into Cambridge Street with the rattle and crash of a fire brigade, we took the bridge across the river at a gallop. Then suddenly we stopped with a lurch. Half the eggs went rolling on the floor, but we were there – at Agassiz's house.

I tumbled out of the carriage, ran up the steps, and pounded on the door. Again and again I beat the door with my fists until at last it was opened by a servant.

"Agassiz," I gasped. "I want Professor Agassiz, quick!" And I pushed my way into the hall.

"Go away. I'll call the police. Professor Agassiz is in bed."

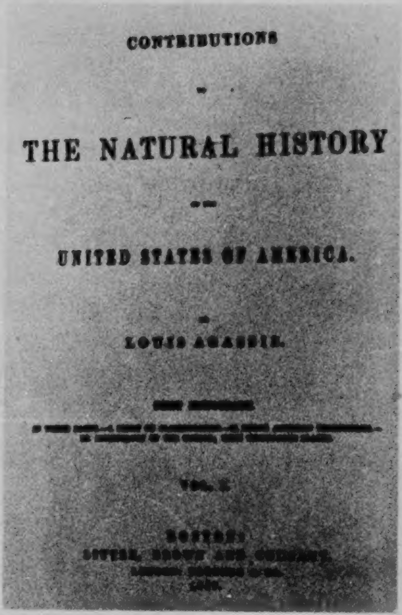
Just then a door upstairs was flung open, and a great white-robed figure appeared on the landing.

"Let him in! I know him. He has my turtle eggs!"

The great man, arms extended, dragged me with my precious pail into his study. With a swift clean stroke he laid open one of the eggs as the watch in my trembling hands ticked its way to seven.

Yes, I was in time!

Agassiz in 1863



CONTRIBUTIONS

THE NATURAL HISTORY

UNITED STATES OF AMERICA.

LOUIS AGASSIZ.

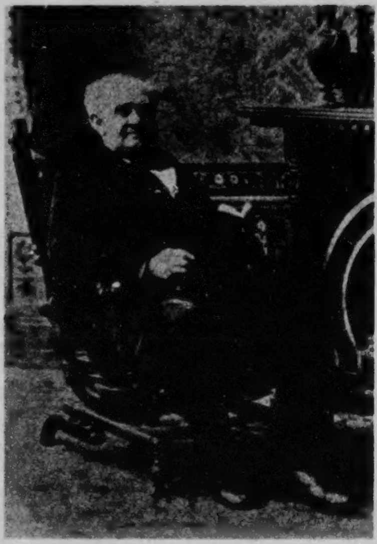
Title page from the book in which Agassiz's report on the turtle eggs appears

THE DINOSAUR MAN

THE DINOSAUR MAN

One October evening in the year 1869 on a farm near Syracuse, New York, two men who had been hired to dig a well came upon the buried stone figure of a giant. He was huge, twelve feet tall, and he weighed more than three tons. The diggers had never seen stone quite like this; it was a variety unknown in the vicinity. Everyone quickly agreed that there was only one explanation for this phenomenon: they had found the petrified remains of a giant who had lived and died in that country ages before.

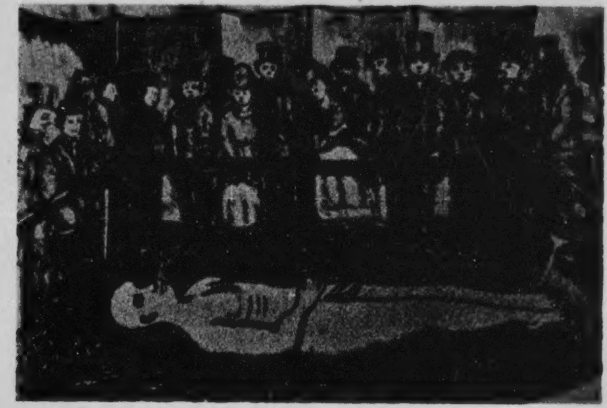
The Cardiff Giant soon became famous — and his owners, prosperous. People came from far and wide, on foot, by horse and buggy, by railroad train to pay their money and see the great monstrosity. P.T. Barnum, of Barnum and Bailey, master showman and famed exhibitor of bearded ladies and dog-faced boys and other similar curiosities, offered to buy this one for more than one hundred thousand dollars - or so it was said. Prominent scientists were invited to inspect the giant.



P. T. Barnum

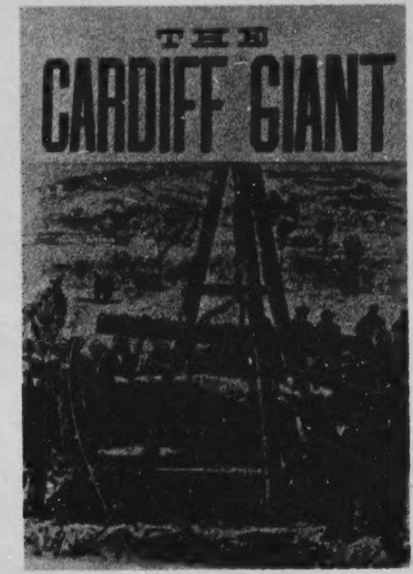
A professor from Rochester said it was genuine and a great find. James Hall, the state geologist, pronounced it the most remarkable object found thus far in America. A professor from Harvard thought he could see Phoenician writing on the figure; he even gave a translation of it.

But then a real spoilsport came along. He was a young professor from Yale who called the giant a fake. It was made of gypsum, he said, and it couldn't be very old because gypsum dissolves rapidly in water. The giant had been found buried in very wet soil; it could not have been there very long in such a perfect state of preservation.



Cardiff Giant

As it turned out, the Yale professor was right, and the other "experts" were wrong. George Hull, a relative of the man on whose farm the giant had been found, admitted that he had quarried the stone from a gypsum bed in Iowa, had it carved in Chicago, and then contrived to bury it at Cardiff just a year before the great discovery was made. It had been a profitable venture. Hull himself cleared $60,000 from the gate receipts and was so encouraged by his brief success that he made another giant out of different material in a secret workshop in Pennsylvania. With the connivance of Barnum, he buried the new giant in Colorado. It was "discovered" as the result of certain hints thrown out by Barnum who just happened to be lecturing on temperance in Colorado at the time. Again, the hoax was exposed by the same Yale professor who was by now getting to be a real authority on such things.



In appearance or just as an idea the Cardiff Giant was not very convincing, so why was it that people in those days were willing to believe in petrified monsters? Not so many would be taken in by such a hoax today, and few persons two hundred years ago would have been likely to accept it. The answer seems to be that nowadays people generally know a little bit more about the sort of fossils to be expected, or that two hundred years ago most had never heard of petrified creatures and thus would not be inclined to believe that the Cardiff Giant was genuine.

In 1869, however, most people knew just enough to make them gullible and not enough to be critical. By that time many genuine fossils, particularly those of extinct animals, had been found. President Thomas Jefferson was an enthusiastic naturalist and fossil hunter: he had found the bones of a mastodon. Moreover, there was scarcely an issue of the American Journal of Science from its founding in 1819 that did not report a new fossil discovery from some part of the country. And just west of Syracuse, especially, one could find all sorts of fossil shells and impressions of ancient plants imbedded in the rocks.

Another thing was that people then paid a lot more attention to rocks than they do now. Our country was believed to have many undiscovered minerals – the finding of gold in California had strengthened this belief. The West was full of prospectors, but even in the East if you were a boy at play in the woods on your farm or a grown man out for a Sunday afternoon walk, you might well do a little prospecting and bring home the interesting rocks you found.

Again, from childhood everyone was familiar with fairy stories and folk tales about monsters – like the giants and dragons that King Arthur's knights slew in order to rescue fair ladies. Sailors had brought home tales of sea monsters, and so on. Perhaps, people said to themselves, there was something to these stories after all.

Still further, the scientists of Europe and America had been carefully studying rocks and the fossils they contained.

They had already discovered that the earth and its climate had often been different at times in the remote past. The ancient Greeks and Romans had noticed seashells in deserts and on hills far above the sea, and they had assumed that there had once been oceans where there was then high or dry land. But the scientists of one hundred years ago had learned much more than this. They had found that what had been topsoil or even sediment at the bottom of lakes or oceans in one period had been later covered over by new layers of soil or sediment and had been transformed into layers of rocks. Trapped and preserved in such ancient rock layers were the plants and animals of successive periods. Some had become petrified; others had decayed and merely left impressions on the rocks. The lowest layers of rocks were thus the earliest ones, farthest removed from our own time. In lower layers one might find only the remains of fishes, higher up mostly reptiles, and still higher, creatures more nearly resembling those of today. In some layers would be found plants and creatures that could only live in a warm tropical climate, and so it was clear that in some periods there had been no marked climatic zones on the earth, and there had been no definite seasons as we know them in the temperate zone today. It was also clear from the record of the rocks that mammals — cows, sheep, elephants, dogs, apes, human beings — were among the latest creatures to appear on earth, and further that when they first appeared they did not look quite the same as they do now. Take the horse, for example: the earliest horses were very small, and they had toes instead of hoofs.

The record of the rocks showed, too, that before our present Age of Mammals there was an Age of Reptiles; that is, a period in which reptiles were the most common creatures on earth. Now, one of the distinguishing features of a reptile is that its young are hatched from eggs that are encased in a protective shell. So are birds, you may say, but reptiles and birds are very close relatives. But birds fly, you object, but so once did some reptiles! Some flying reptiles were so big they were indeed dragons. Again you may say that many reptiles have teeth, but so did some birds once upon a time.

What reptiles can you think of? Turtles, crocodiles, lizards, snakes? True, but in the Age of Reptiles there were not only some that flew like birds, but also some that looked like mammals, and others that looked like fish. Most spectacular of all were the fierce lizards, the dinosaurs. Many of these were huge creatures: some of them ate trees and plants, while some ate other dinosaurs or any living thing they could catch.

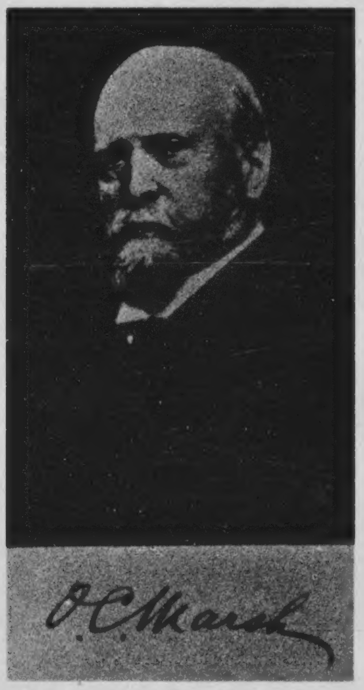
Most of you know a lot about dinosaurs. You've seen pictures of them; you've seen toy models of them; and you may even have seen their skeletons put back together again in a museum.

And that brings us to our story . . .

Who proved that the Cardiff Giant was a fake? Who found the three-toed horse and showed how horses changed in the course of millions of years until they became like the ones we know today? Who discovered "Birds with Teeth" and called attention to them as connecting links between birds and reptiles? Who was the first professor of paleontology (the study of fossil bones) in the United States? Who was the first to make restorations of fossil creatures and display them in the first museum of paleontology in this country? Who discovered Flying Dragons?

One man did all these things! He was the first and probably the greatest specialist in his field our country has ever produced. He was world-famous: he knew Charles Darwin and Queen Victoria, President Grant and Buffalo Bill, and he was the special friend of the fierce Sioux chieftain, Red Cloud.

Who was he? His name was Othniel Charles Marsh, and he was truly the Dinosaur Man!



O. C. Marsh

A great sportsman, a crack shot, a superb fisherman, a fine horseman, absolutely without fear, Marsh lived at a time when all these qualities were not only admired, but also required, especially for anyone who wished to travel and explore in our then very Wild West. These were exactly the qualities that later on led Theodore Roosevelt to the White House. The Wild West was somewhat tamer in Roosevelt's day, but when Marsh sought fossils and excitement on the Great Plains and in the Badlands and the Rocky Mountains right after the Civil War, the West had not been won. Those were the days of cowboys and Indians, the great trail drives, the huge buffalo herds, and the building of the first transcontinental railroads. It was a time of high adventure.

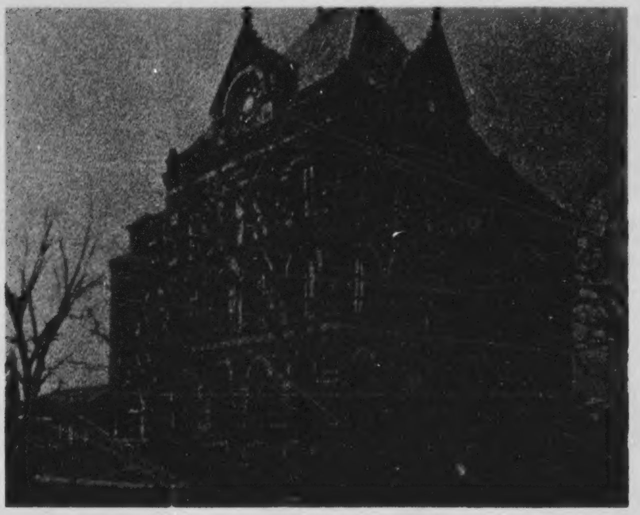
Othniel Marsh was born in Lockport, near Buffalo, New York, in 1831. His parents were New Englanders who had come out to farm the fertile lands of the Niagara Frontier. While Caleb, Othniel's father, was a cautious, conservative man, Caleb's brother John was not. After graduating from Harvard College in 1823, John had journeyed to Fort Snelling, a frontier post in Minnesota, to teach the children of the commanding officer there. It was John Marsh who established the first school in Minnesota, but he was a wanderer at heart and soon moved on to St. Louis, then Santa Fe, and finally California where he arrived before the gold rush and in the end became a rich man.

Nevertheless, in the matter of wealth John Marsh could not compete with his brother-in-law, George Peabody, who was a millionaire many times over, and however much Othniel

Marsh was influenced by the adventurous example of his Uncle John, his career was more affected by the wealth and generosity of his Uncle George who never married but took exceedingly good care of his brothers and sisters and nephews and nieces. Othniel's mother was the sister of George Peabody, and it was George Peabody who paid for Othniel's education both in the United States and in Europe, who provided the money for the great museum of paleontology, and who left his nephew an inheritance so large it took him more than thirty years to spend it.

Let us hasten to add, however, that George Peabody was more generous to Othniel Marsh than to his other relatives

The Peabody Museum of Natural History



First Museum 1876-1917

because of them all Othniel pleased him most by doing well at school and by showing a desire to make something of himself by hard work. It should also be said that George Peabody, like Andrew Carnegie and John D. Rockefeller, was a great philanthropist. He gave millions to improve housing conditions for the poor in London, England, and he left more millions for the education of Negroes in our southern states after the Civil War.

Growing up in Lockport near the banks of the Erie Canal, the big ditch completed in 1825 and then the major highway across New York State, Othniel showed little interest in work on the farm or work in school. Instead, he was fascinated by a neighbor, Colonel Ezekiel Jewett, a veteran of the Mexican War, a great marksman, and a man much interested in geology and the marine fossils so plentiful in the layers of shale revealed by the digging of the Erie Canal. Although Othniel and his father were touched by "gold fever" and nearly went to California to join Uncle John, in the end the boy decided to pursue his education in New England. Since Othniel's mother had died, Uncle George Peabody felt obliged to help his sister's son.

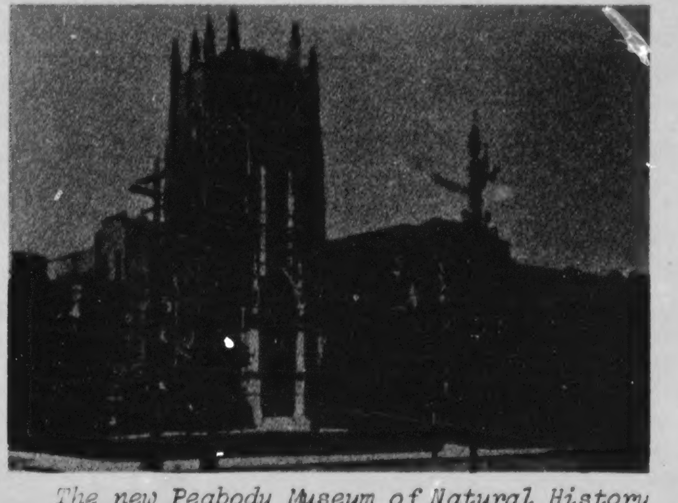
So it was that at the age of twenty, Othniel Marsh entered Philips Academy in Andover, Massachusetts. In those days an academy was roughly the same as a senior high school now. Consequently, Othniel was somewhat older than the other boys in the school, and once he settled down and decided to work, his age gave him an advantage as a student and as a leader among his younger classmates. Needless to say, he graduated with honors.

In those days, unlike the present, few people expected to go to college. In fact, most people never went to school beyond the sixth grade. At Philips Academy, however, things were different. The students planned on college, and this meant pretty much going to Harvard or Yale. Othniel chose the latter because it was known to be very strong in science, his major interest. He did well at Yale, graduating in 1860 eighth highest in his class, and once again he found himself among younger men. They called him "Captain" and "Daddy," but they respected him for his ability as a student, his skill in out-of-doors activities, and his qualities of leadership. He studied geology under James Dana, then the foremost of American geologists, and became so interested in the field that he stayed on at Yale for two more years to do graduate work in the newly organized Sheffield Scientific School. One of his major subjects of study was mineralogy, again a field in which Dana had a great and well-deserved reputation.

By 1862 the Civil War was raging fiercely. Marsh tried to enlist for service, but he was rejected because of poor eyesight. Therefore he decided to embark upon further scientific studies in Germany – with Uncle George's help, of course. The German universities were then the best in the world for training in science; most of the important American professors had studied there for a time.

Marsh spent three years abroad. His major work was at Berlin, but he also spent some time at Heidelberg and Breslau. While his intention had been to go on with mineralogy, he became attracted to zoology and might have done more with it except that Dana and others at Yale advised him to specialize in paleontology and dangled before him the promise of a professorship in that subject if he would qualify himself for it.

In 1866 the professorship finally materialized, partly due to the fact that Othniel had persuaded Uncle George to give $100,000 to build a museum at Yale for "Natural History." This would include the Departments of Zoology, Geology, and Mineralogy — and Paleontology. Marsh came back to the United States full of knowledge and enthusiasm and bringing the two and one-half tons of books and fossils he had purchased in Europe. It was a good start for a museum and library in palaeontology. Even today a paleontologist cannot work without his books and his bones!



The new Peabody Museum of Natural History opened to the public in 1926

So far — so good, but what next? Marsh was not expected to do any teaching at Yale. The museum had not been built; it would not be built for ten years. Marsh had read books; he had listened to lectures; he had observed fossils in museums; he had made a couple of field trips to Nova Scotia to study mineralogy. He had published a half-dozen little articles on mineralogy, fossils, and an Indian burial mound in Ohio. This really wasn't much for a grown man of thirty-five who was a professor at Yale. Thus far the whole thing had been a gamble, but now the chips were down. Would Othniel justify Uncle George's expectations, or would he simply fritter away his time in the pleasant society of friends in New York and New Haven?

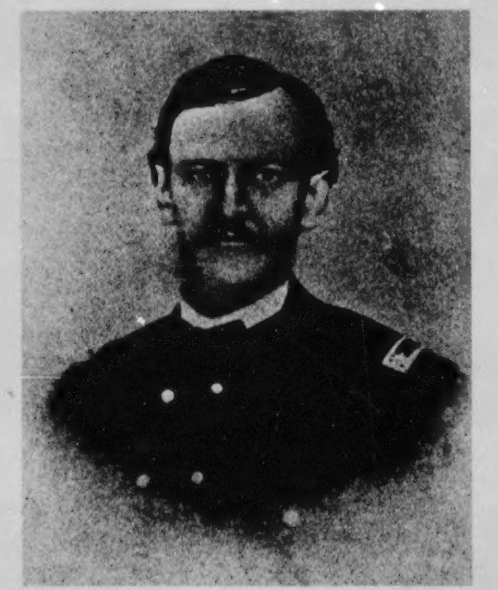
There was no immediate great explosion. In 1866 and 1867 Marsh journeyed up the Connecticut River Valley to the vicinity of Greenfield and Turners Falls in Massachusetts in order to look at the dinosaur footprints visible in the rocks along the river bank. Collecting for his museum, he eventually hauled off to New Haven two freight car loads of print-bearing rocks. The next year, 1868, Marsh went on a fossil collecting trip in New Jersey in company with Edward Cope, a good paleontologist who was destined to be Marsh's rival and finally his bitterest enemy.

During this same period after his return from Europe, Marsh had been diligent in attendance at the annual meetings of the American Association for the Advancement of Science, the AAAS. In 1868 he went to the AAAS meeting in Chicago where he read three papers and was elected secretary of the society, but what happened after the meeting proved to be far more important:

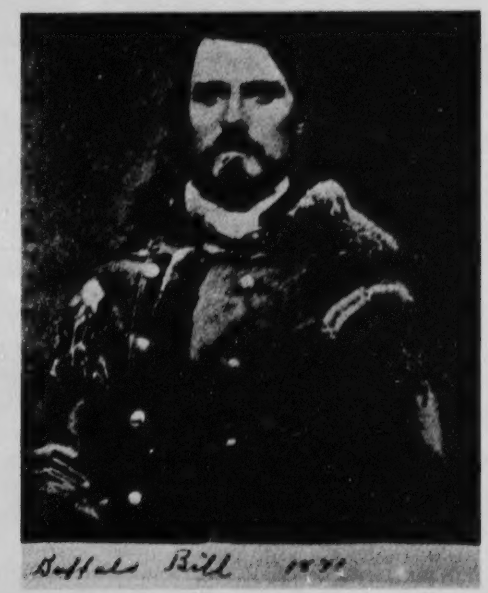
Several excursions were offered to AAAS members. One of these was to Omaha, Nebraska, and from there Marsh took a trip on the Union Pacific Railroad to the very end of rail construction in Wyoming. For the first time he saw the West and began to realize its possibilities for paleontology. In particular, he made a stop at Antelope Station, Nebraska, where it was reported that "fossilized human remains" had just been found. At Antelope Station Marsh collected a hat-full of bones. Now his European training paid off, for he saw at once that these were not "human remains" but rather the bones of a tiny fossil horse. Full grown, the animal had been only three feet high, "and each of his slender legs was terminated by three toes." This was the beginning! In the next few years Marsh was to find other fossil horse bones which enabled him to put together the animals in a series that told the story of the horse from its origins as four-toed creature about the size of a fox to the relatively huge hoofed animal of today walking about on what had once been its third toe. This was one of Marsh's earliest research projects. It brought him international fame and earned for him the respect of paleontologists in Europe and America.

But the western trip of 1868 had further repercussions. Marsh was determined to return and explore the marvelous country he had seen from the train. Each year between 1870 and 1874 he was to make collecting expeditions into the West. That these were profitable and important we shall soon discover.

Army Scouts with the Expedition of 1870

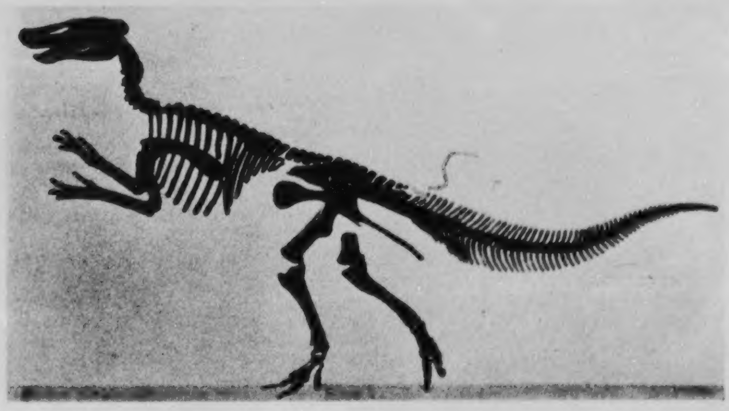


Major Frank North



Col. William F. Cody
(Buffalo Bill)

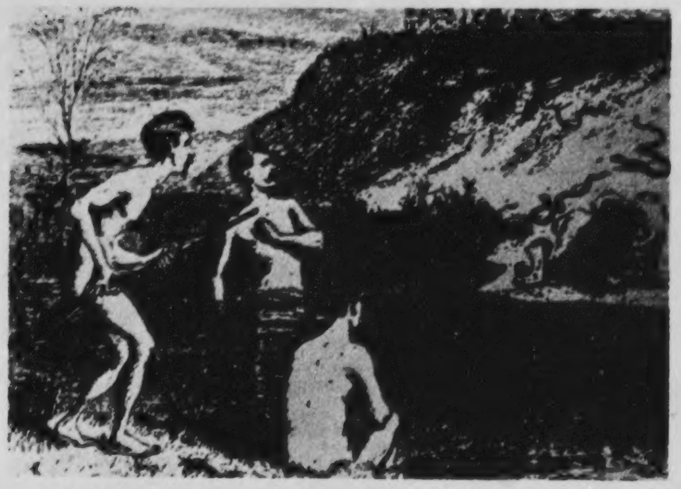
In 1870 Marsh led a party of a dozen Yale students on a six-month fossil-hunting trip on horseback through parts of Nebraska, Colorado, Wyoming, Utah, and Kansas. Included in this hardy group were Eli Whitney, grandson of the great inventor; James Wadsworth, future congressman and member of a politically prominent up-state New York family; and



CLAOSAURUS ANNECTENS Marsh, the first dinosaur skeleton to be mounted in America; found in Niobrara County, Wyoming, in 1891

Charles Reeve of Minneapolis, later to serve in the Minnesota state legislature and to become the first chief of police in Manila after the Spanish American War. Armed to the teeth and accompanied by a large military escort provided from various frontier posts by order of the War Department, the party made its way through the territory of hostile Indians. It was on this trip that Marsh first met Buffalo Bill who became one of his lifelong friends.

One of the first stopping places of the expedition was Antelope Station where Marsh collected more bones and where the party had to camp in country that was literally crawling with rattlesnakes. This was typical of the long and arduous trip which continued until the onset of winter. Thanksgiving



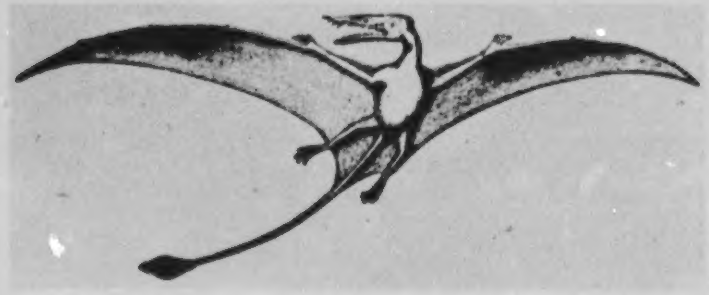
The rattlesnake peril
From a woodcut in Harper's New Monthly Magazine

time found the explorers in Kansas among the great buffalo herds. Riding in an army wagon drawn by mules that almost stampeded every time a shot was fired, Marsh brought down two buffalo with as many well-aimed shots, but when he dismounted and went on foot to examine his third victim the animal got up and charged him. A final shot brought the buffalo down for good, but Marsh's career had been very close to finished.

In Kansas the party found the bones of the thirty-foot long mosasaurs, sea serpents that inhabited the ocean covering Kansas at the end of the Age of Reptiles, and there in Kansas Marsh also discovered a strange and puzzling fossil bone. It was hollow, about six inches in length, and at one end was a curious kind of joint that Marsh had never seen before. Since darkness was coming on, he had no time to search for other bones at this spot so he marked a nearby rock to identify the site, wrapped up the bone and took it back to camp.

The hollow bone puzzled Marsh. Because it was hollow, it seemed that it should belong to a bird, but what bird would have a bone six inches long in its wing? Back in New Haven he puzzled over the bone again and compared it with specimens he had brought from Europe. The only bones with such strange joints were found in the wing fingers of Pterodactyls, flying lizards, but all the known European specimens were tiny little creatures with bones one-twentieth the size of this one. Yet, there seemed to be no other explanation: the bone had belonged to a gigantic flying dragon with a wingspread

The Flying Dragon



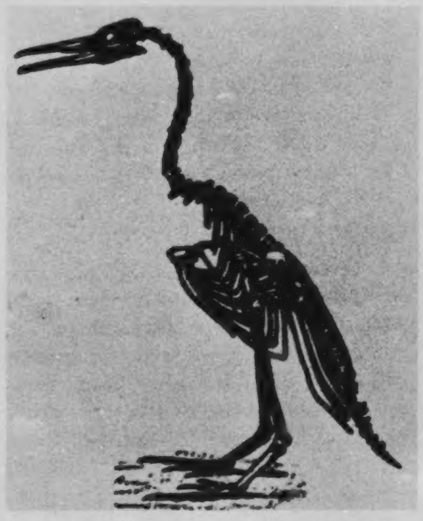
Restoration
published by
Marsh, 1882

Original specimen,
in Yale Peabody Museum

of at least twenty feet. Convinced that he was right, Marsh published a description of his new creature, based on the evidence of a single bone; he even provided his dragon with a scientific name. In the expedition of 1871, he returned to Kansas, found the mark he had made on the stone, searched the vicinity, and discovered the rest of the bones belonging to the wing of the flying reptile. The creature proved to be fully as large and exactly the same as he had predicted!

The pterodactyl was a flying reptile without teeth. This was rather strange but no stranger than the combination Marsh found in the same part of Kansas in 1872 – a bird with teeth but lacking wings! This new specimen lived in the sea that once covered a large part of the Great Plains. It was a great diving bird that used its sharp teeth for catching fish; in addition, it did not swim like a duck or a loon but used its legs like oars instead of paddles. This discovery and others like it led Marsh to another important research project which he completed and published in 1880 and again earned the applause of the scientific world. His book was called Odontornithes (Birds with Teeth), Extinct Birds of North America.

In 1874 Othniel Marsh made his last fossil-hunting expedition to the West with his Yale students. Even then, it was a dangerous undertaking. The Indians were restless and bitter and on the verge of revolt. Gold had been discovered in the Black Hills, in territory that had been given to the Indians, and also people were wanting to build a railroad

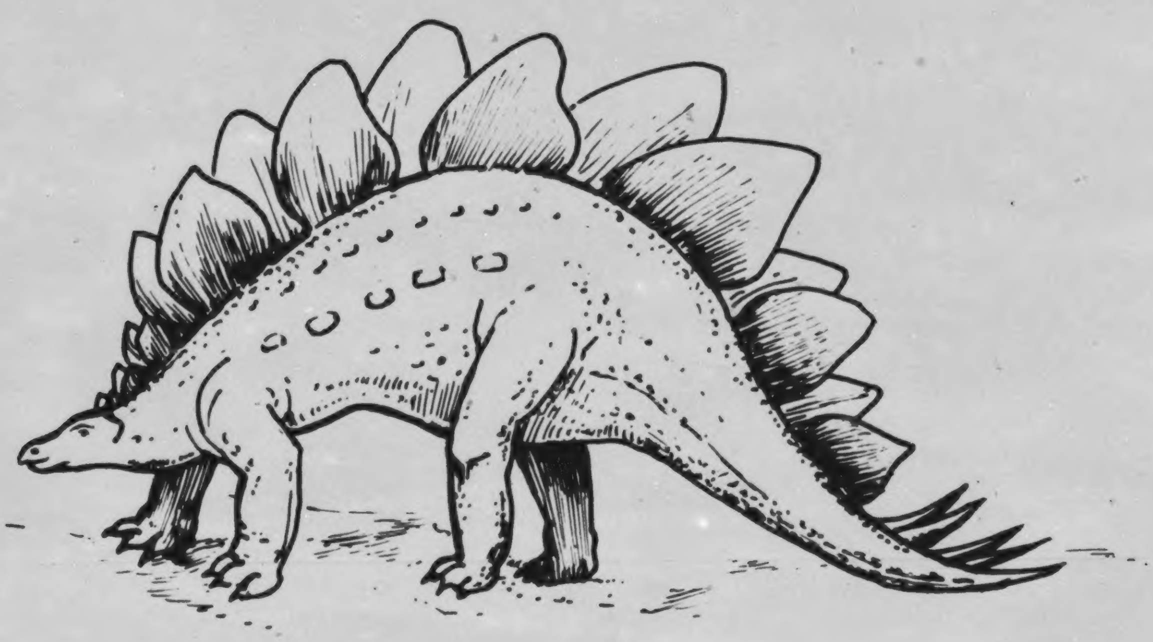


Diving Bird
Illustration from Odontornites

through Indian territory in North Dakota and Montana. Against all advice, Marsh made a daring march through Indian territory to collect fossils. On his return to the nearest frontier fort, however, he had a long talk with the Sioux chief, Red Cloud, who showed him the inferior beef, flour, and other supplies that had been provided the Indians by corrupt government agents who had been embezzling the money sent by the Congress to buy supplies for the Indians. Marsh was angry, and he promised Red Cloud that he would take the matter to President Grant himself. And he did! Almost single-handed, Marsh fought the dishonest bureaucracy in Washington and brought about the resignation of the Secretary of the Interior, a time-serving politician, and many others in the Bureau of Indian affairs.

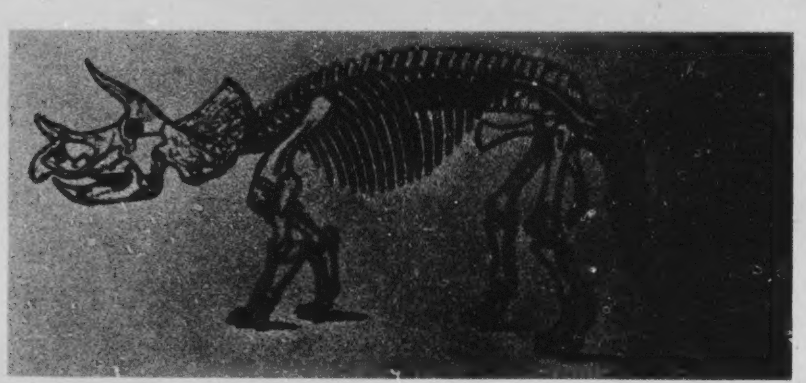
But it was too late. In 1875 the Sioux went on the warpath, and in 1876 General Custer and his men were massacred at the Little Big Horn. It was no time to be hunting fossils in the West. Marsh never went out again. Instead, he hired many people in various localities to collect the bones for him and send them to New Haven where they could be studied.

The new procedure worked well. In 1877 Marsh's "bone collectors" sent him from Colorado and Wyoming the bones of gigantic dinosaurs: the Atlantosaurus, a huge plant-eating reptile at least sixty feet long, and the Stegosaurus, an armored lizard weighing many tons and equipped with two tiny brains – one in its head, and one in its tail!



The Stegosaurus was so impressive that it even moved a "poet" to write:

Behold the mighty Dinosaur,
Famous in prehistoric lore
Not only for his weight and length
But for his intellectual strength.
You will observe by these remains
The creature had two sets of brains,
One in his head (the usual place),
The other at his spinal base.
Thus he could reason *a priori*
As well as *a posteriori*.
No problem bothered him a bit,
He made both head and tail of it.
So wise was he; so wise and solemn,
Each thought filled just a spinal column.
If one brain found the pressure strong,
It passed a few ideas along.
If something slipped his forward mind
'Twas rescued by the one behind.
And if in error he was caught,
He had a saving afterthought.
As he thought twice before he spoke,
He had no judgement to revoke.
For he could think without congestion
Upon both sides of every question.
Oh! Gaze upon this model beast,
Defunct ten thousand years, at least.

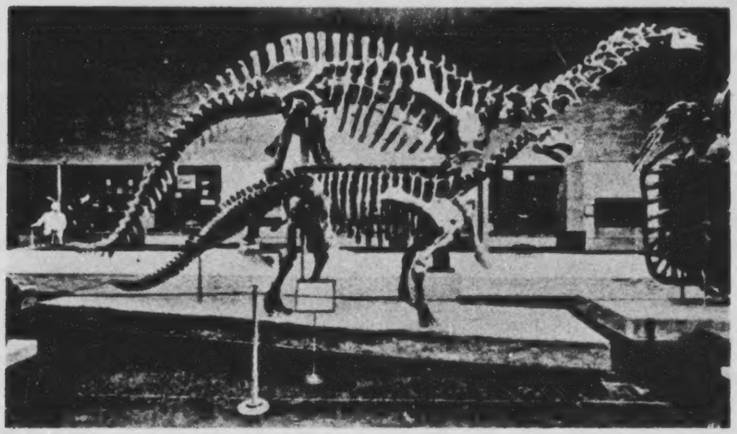


Marsh's restoration of a fossil find

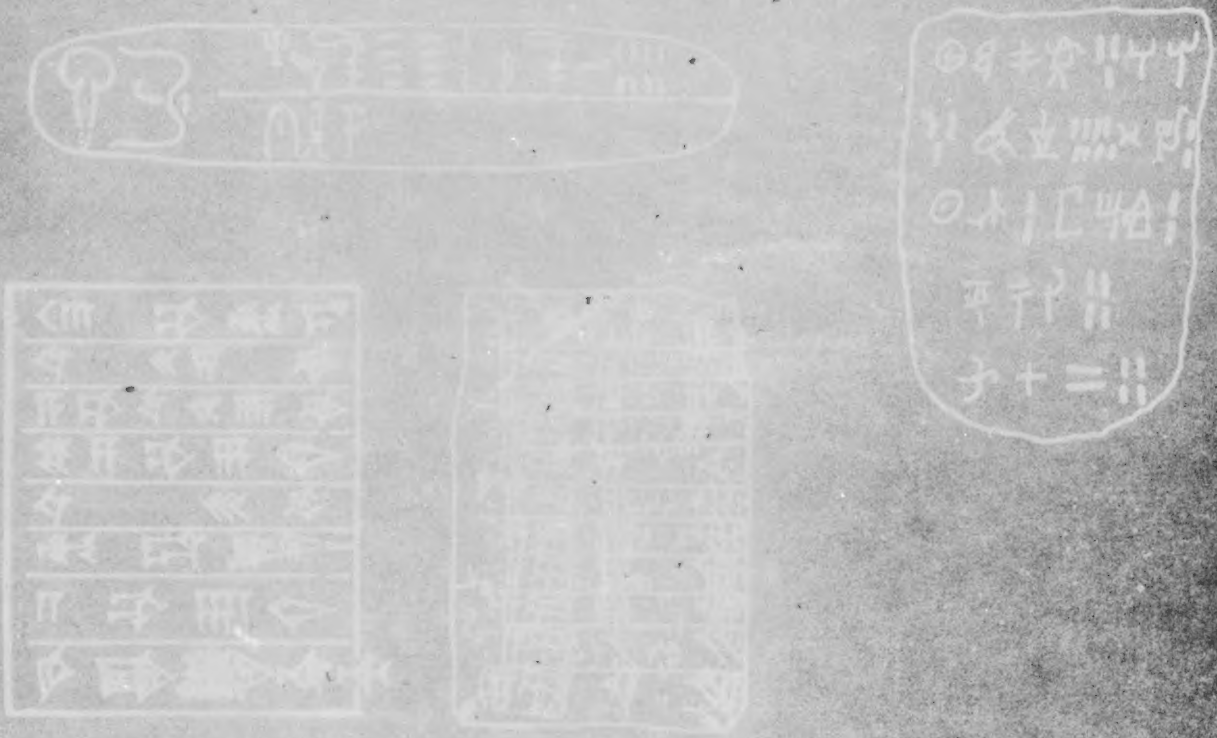
By the 1880's Othniel Marsh had run his course as a scholar. In ten years he had done so much that other people were to make all kinds of demands on his talents. Always a manager and a leader, he could not resist the opportunities for service to others that were forced upon him. Between 1883 and 1895 he served as president of the National Academy of Sciences and had to make many fateful decisions that added to the stature of the National Academy and were useful to the country. He was made honorary curator of paleontology in the National Museum at Washington, D.C., and he collected many fossils for the museum which you can see when you go there today.

Othniel Marsh gave his money and he gave himself, and it is sad to relate that he got little in return. Political pressures forced him out of the United States Geological Survey and the National Museum. With Uncle George's money spent, he had to sell his house in New Haven and accept a salary from Yale University which had used him and Uncle George's money for thirty years. Yale had profited by several million dollars from George Peabody and the collections made by Othniel Marsh, but this is the way of the world.

Marsh died of pneumonia in 1899. He was almost a pauper, and he had no wife or children to accompany him to his grave. A lonely man, even a difficult man, he was nevertheless great, as giant as his dinosaurs. He was indeed the Dinosaur Man!



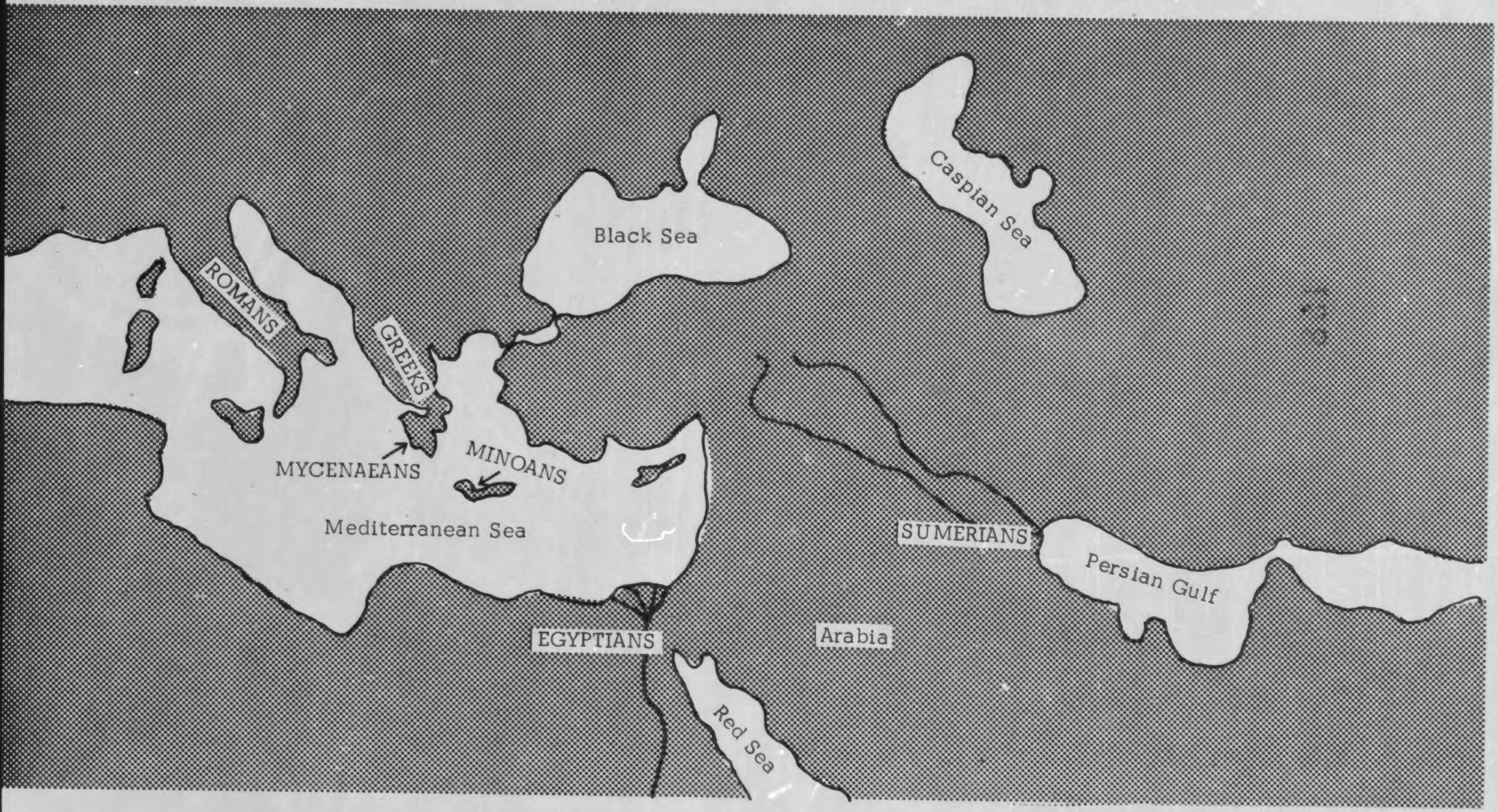
This is the mounted skeleton of the great Sauropod Dinosaur. It was collected in 1881 by W. H. Reed at Como, Wyoming. A much smaller Como Sauropod, 21 feet long, is to be seen in the foreground.
Peabody Museum of Natural History



COUNTING, RECORD-KEEPING, AND ANCIENT SYSTEMS OF NUMERICAL NOTATION

ΣΥΡΙΟΙ
ΠΥΛΑΙΕΣ
ΠΙΤΑΝΑΙΟΙ
ΟΙΝΑΙΟΙΕΧΣΙΚΑΡΟ
ΦΟΚΑΙΕΣ
ΗΑΙΡΑΙΟΙ
ΜΥΡΙΝΑΠΑΡΑΚΥΜΕ

Where the systems of notation were used (3000-300 BC)

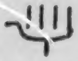
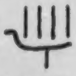
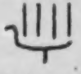

ROMANS
GREEKS
Black Sea
Caspian Sea
MYCENAEANS
MINOANS
Mediterranean Sea
SUMERIANS
Persian Gulf
EGYPTIANS
Arabia
Red Sea

COUNTING, RECORD-KEEPING, AND ANCIENT SYSTEMS OF NUMERICAL NOTATION

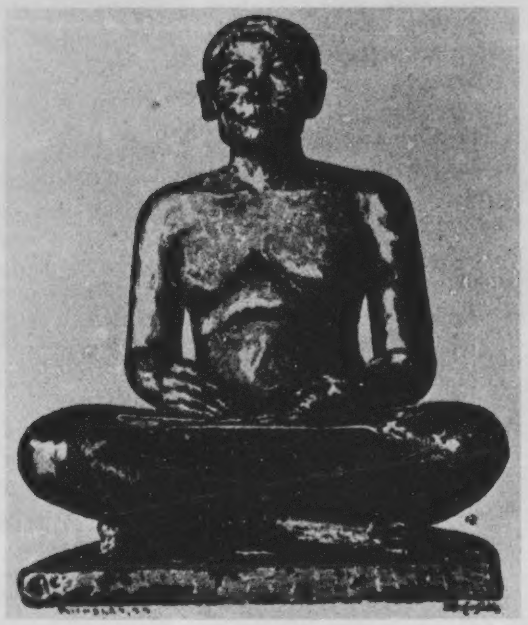
We play many games in which we have to keep a score, and very often when the points are scored one at a time we use a system like this:

one /
two //
three ///
four ////
five 𝍸

This is good for quick counting because we can see at a glance that 𝍸 𝍸 𝍸 is fifteen or that 𝍸 /// is eight, but if we simply wrote /////////////// or //////// we would have a hard time counting the points in a hurry.

The fact that we have five fingers  on each hand and ten fingers in all   has a lot to do with the system of counting we use. It is called the decimal system and in it ten is the most important unit. If we had four fingers or six fingers on each hand, we would probably not use the decimal system at all. Even our coins might be different. There might be four or six pennies in a nickel, or eight or twelve pennies in a dime, or sixteen or thirty-six pennies in a dollar.

As everyone knows, we have figures or symbols, as well as words, for the numbers, and we now use what are

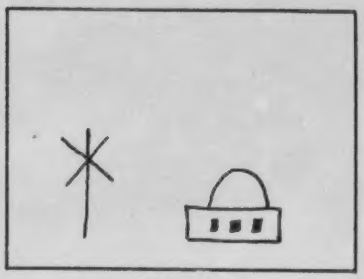

Cross-legged scribe (Old Kingdom)

called the Hindu-Arabic numerals: 1, 2, 3, 4, 5, and so on.

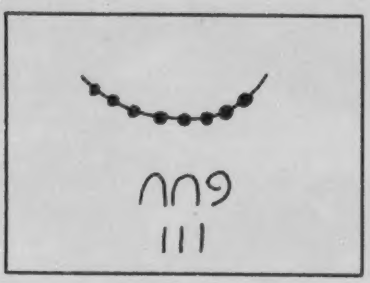
But not everyone in the world uses these figures or numerals today. Moreover, five hundred years ago not all of our ancestors used the Hindu-Arabic numerals either.

Five thousand years ago, when people were just beginning to write and to put down numerals to keep track of their sheep and goats and cattle and their quantities of barley, wheat, or rice, they used symbols for the numbers that were not like ours at all.

Here are drawings of an ivory label or tag that was found attached to a necklace in an old Egyptian tomb (about 3000 B.C.).

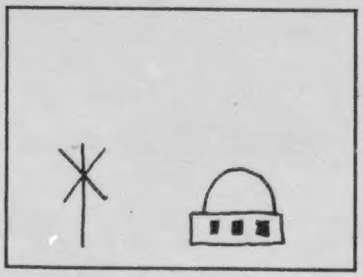


Front

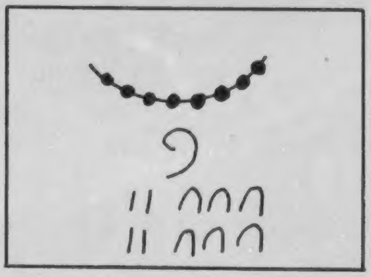


Back

And here is another tag from the same tomb:

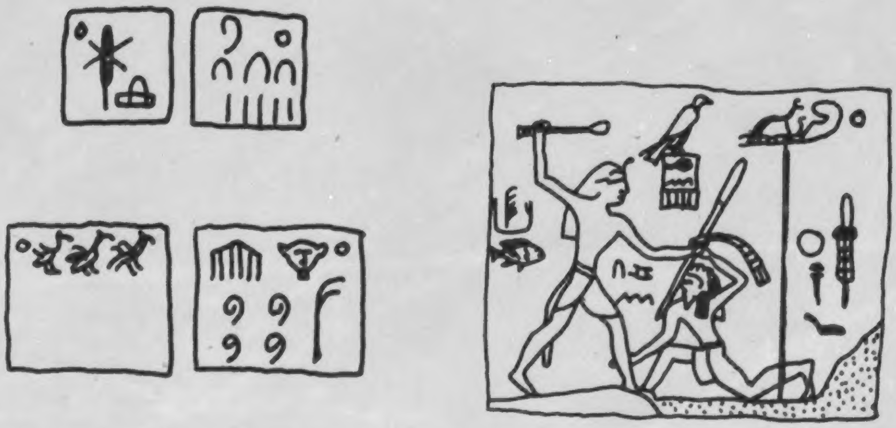


Front



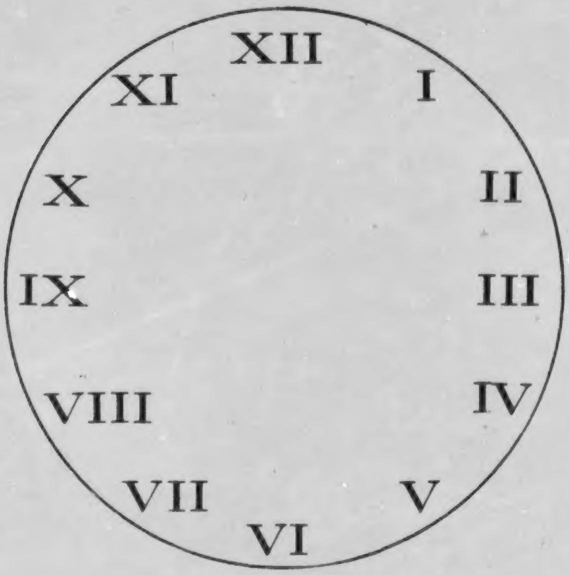
Back

Tags found in Egyptian tomb



On the front of both labels you see the same symbols. This is the way the old Egyptians wrote the name of the queen who was buried in the tomb and to whom the necklaces belonged. On the back of each label you see the representation of a necklace along with other signs which stand for numbers. The first number is 123, the number of beads in the necklace to which the label was attached. How many beads were there in the second necklace?

Here is the face of a clock. Can you read the numerals? Do you know what IV, V, VI and IX, X, XI stand for?



These, as you probably already know, are called Roman numerals. They were used by the old Romans more than two thousand years ago, and they continued to be used by people in Europe until the Hindu-Arabic numerals began to be popular shortly before the time when Columbus discovered America.

The I, V, X and combinations of these symbols were not the only letters that the Romans used as numerals. Let's see if you can figure out the meaning of some of the others. If you had been a child in a Roman school, you might have had to do problems like these:

$$\begin{array}{r} \mathrm{III}\\ \mathrm{II}\\ \underline{\mathrm{V}}\\ \mathrm{X}\end{array}\qquad \begin{array}{r} \mathrm{V}\\ \underline{\mathrm{X}}\\ \mathrm{XV}\end{array}\qquad \begin{array}{r} \mathrm{I}\\ \mathrm{V}\\ \underline{\mathrm{X}}\\ \mathrm{XVI}\end{array}\qquad \begin{array}{r} \mathrm{II}\\ \mathrm{II}\\ \underline{\mathrm{V}}\\ \mathrm{IX}\end{array}\qquad \begin{array}{r} \mathrm{X}\\ \underline{\mathrm{VI}}\\ \mathrm{IV}\end{array}\qquad \begin{array}{r} \mathrm{X}\\ \underline{\mathrm{V}}\\ \mathrm{XV}\end{array}$$

Suppose you had a problem like this:

$$\begin{array}{r} \mathrm{XX}\\ \mathrm{XX}\\ \underline{\mathrm{X}}\\ \mathrm{L}\end{array}$$

What do you think L stands for?

Or C in this one?

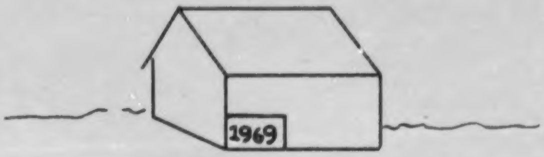
$$\begin{array}{r} \mathrm{L}\\ \mathrm{XXX}\\ \underline{\mathrm{XX}}\\ \mathrm{C}\end{array}$$

Roman coin with numerals

What kind of problems are these?

$$\begin{array}{c} \text{X} \\ \text{X} \\ \hline \text{C} \end{array} \qquad\qquad \begin{array}{r} \text{VIII} \\ \text{V} \\ \hline \text{XL} \end{array}$$

You have seen buildings that have cornerstones which have a date that tells when the building was constructed. This one was built in 1969.



Sometimes Roman numerals are used instead of the Hindu-Arabic ones for the same purpose. A building dating from the Civil War might have this date:

MDCCCLXI

Or one built the year George Washington was born might read like this:

MDCCXXXII

This cornerstone would be from the year Columbus discovered America:

MCDXCII

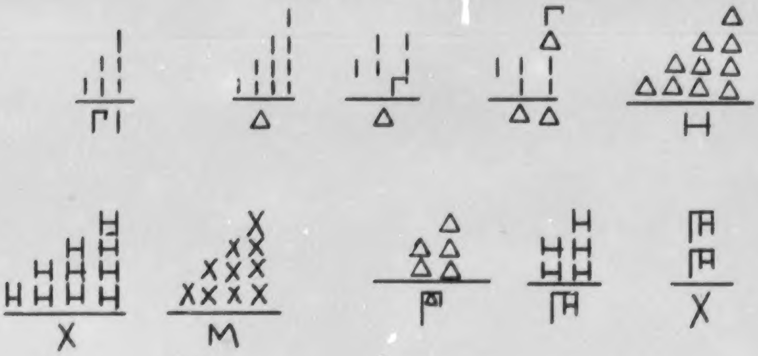
Do you see what M and D stand for? And if IV is 4 and IX is 9, or XL is 40, what are XC and CD?

Below is the inscription on the tombstone of a young Roman. It was set up by his parents, and in the fifth line we learn that he lived so many years, months, and days. Can you tell how old he was?

D M
VRBANO · AVG · VERN
ADIVTORI · TABVLARI
RATIONIS · PATRIMONI
VIXIT · ANN S · XXI · M · VII · D · XXXII
TYRANNVS · AVG · L B
ET · AELIA · VRBANA
PARENTES
FILIO · KARISSIMO

Roman coins with numerals

Now, let's look at a different system, the one used by the ancient Greeks who invented it several hundred years before the time of the Romans:



Can you see what |, Γ, Δ, H, X, M stand for? Or 𐅄 and 𐅅 ?

If the numerals below stood for a date, what would it be?

MHHHH𐅄ΔΔΔΔ||

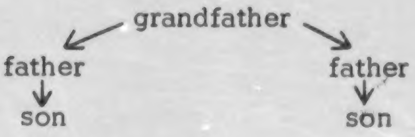
Before we go on, let's see what we have found out so far:

Hindu-Arabic	Roman	Greek
1	I	|
5	V	Γ
10	X	Δ
50	L	𐅄
100	C	H
500	D	𐅅
1000	M	X

Below is a Greek inscription on stone. It records sums of money. The coins involved are the drachma and the obol. There were six obols in a drachma. The number of obols is indicated by the vertical strokes, while all other figures refer to drachmae. Thus, ⊢ stands for one drachma, and ΔΓ⊢|||| is to be read 16 drachmae and 4 obols.

	Ο		ΕΛ
	·ΙΟΙ		·ΕΝΔ
	ΕΣ		ΝΕΑΓΟL
	·ΕΣ	ΔΓ⊢IIII	ΣΚΑΦΣΑ
	ΣΥΡΙΟΙ	ΔΓ⊢IIII	ΣΚΙΑΘ
	Α𐌆ΟΜΕΝΙΟΙ	ΔΔΓ	ΙΚΙΟΙ
	ΓΥΛΑLΕΣ	ΔΔΔ⊢⊢⊢II	ΟLΟΦ·
.Γ⊢IIII	ΓΙΤΑΝΑΙΟΙ	ΔΔΔ⊢⊢⊢II	ΔΙΚΑ
ΓΔΓ⊢IIII	ΟΙΝΑΙΟΙΕΧΣΙΚΑΡΟ		ΓΑ
Η𐅄	.ΟLΟΦΟΝΙΟΙ	ΔΓ⊢IIII	
·IΓΔΔΔΓIIIII	ΦΟΚΑΙΕΣ	Η	Σ
Η	ΗΑΙΡΑΙΟΙ	Η	ΔΙΕΣΗ
Η	.Ε.ΕΔΙΟΙ	Η	ΣΤΡΕΦΣ
Η	ΜΥΡΙΝΑΓΑΡΑΚΥΜΕ:	'Η𐅄	ΛΑLΕΦΣ
ΓII	ΤΕΙΙΟΙ	𐅄	ΝΕΟΓΟL
𐅅ΗΗΗΗ	ΚΥΜΑΙΟΙ	ΔΔΔ⊢⊢⊢II	ΑΙΛΑΝΤ
ΔΓ⊢IIII	.LΑΙΕΑΡΑΡΑΜΥ	Η	ΜΑΡΟΝΙ
Γ⊢⊢⊢II	ΓΡΙΑΓΟΣ	ΔΓ⊢IIII	ΣΑΝΑΙΟ
Γ⊢⊢⊢II	ΓΑLΑΙΓΕΡΚΟΣΙΟ	ΗΗ	ΒΟΤΤΙΑ
Γ⊢⊢⊢II	ΛΕΝΤΙΝΙΟΙ	ΗΗΗ	ΓΕΓΑ
ΔΓ⊢IIII	ΓΕΡΚΟΤΕ	ΗΗ	^ ΝΛ·
Γ⊢⊢⊢II	ΤΥΡΟΔΙ𐌆Α	Η	ΑΦΥΤΑΙ
ΔΓ⊢IIII	ΔΑΜΝΙΟΤΕ ΙΤΑ	IIII	ΜΕΚΥΒΕΡΝ
ΔΓ⊢IIII	ΔΙΔΥΜΟΤ		ΟLΥΝΘΙΟΙ
ΔΓ⊢IIII	ΒΕΡΥ	⊢⊢⊢II	ΣΚΑΒLΑΙΟΙ
ΔΓ⊢IIII	LΑ	ΔΔΔ	ΗΑ·ΣΣΕΡΙΤΑΙ
ΔΓ⊢IIII	Γ		ΔΙΚΑΙΑΕΡΕΤΡΙ
ΔΔΔ⊢⊢⊢II	Ν	𐅅Η	ΤΟΡΟΝΑΙΟΙ
		ΗΗΗ	ΑΚΑΝΘΙΟΙ
		Η	ΑΡΛΙLΙΟΙ
		𐅅Η	ΣΚΙΟΝΑΙΟΙ
		ΔΓ⊢IIII	ΟΡΑΜΒΑΙΟΙ
		ΔΓ⊢IIII	ΦΕΛΕΤΙΟΙ
		ΗΗΗ	ΑΙΝΕΑΤΑΙ

Just as people do not – and never did – all use the same symbols for numerals, so also the words for the numbers are not the same in the various languages. There are, however, families of languages, and the members of a given language family can trace themselves back to a common ancestor just as people can:



(the fathers are brothers)

(the sons are cousins)

Cousins may look very much alike. Related languages also have words that are very similar. We can see relationships among the languages if we compare the words they use for the numbers.

One huge family of languages is called Indo-European. Within this great family is a smaller group of closely related languages called Indo-Germanic. If we compare English and German with their common ancestor, Gothic, we can see the relationships:

Gothic	German	English
ains	ein	one
twai	zwei	two
-- (unknown)	drei	three
fidwor	vier	four
fimf	fünf	five
saihs	sechs	six
sibun	sieben	seven

ahtau	acht	eight
niun	neun	nine
taihun	zehn	ten

We can do the same thing with the Romance languages — Italian, Spanish, Portuguese, and French — which had a common ancestor, Latin, the language of the Romans.

Latin	Italian	Spanish	Portuguese	French
unus	uno	un	um	un
duo	due	dos	dois	deux
tres	tre	tres	tres	trois
quattuor	quatro	cuatro	quatro	quatre
quinque	cinque	cinco	cinco	cinq
sex	sei	seis	seis	six
septem	sette	siete	sete	sept
octo	otto	ocho	oito	huit
novem	nove	nueve	nove	neuf
decem	dieci	diez	dez	dix

Moreover, within the larger Indo-European family similarities can be discovered:

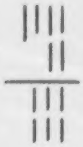
Greek	German	English	Latin	French	Spanish
hen	ein	one	unus	un	un
duo		two	duo	deux	dos
hex	sechs	six	sex	six	
hepta	sieben	seven	septem	sept	
okto	acht	eight	octo		ocho
deka			decem	dix	diez

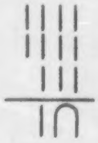
Other number words and the way in which they are formed are interesting, too:

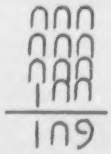
Greek	Latin	Italian	French	German	English
hendeka	undecim	undici	onze	elf	eleven
dodeka	duodecim	dodici	douze	zwölf	twelve
eikosi	viginti	venti	vingt	zwanzig	twenty
hekaton	centum	cento	cent	hunderd	hundred
chilioi	mille	mille	mille	tausend	thousand

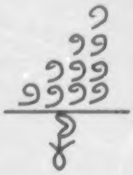
Vignette from the Book of the Dead from the papyrus of Dûnefer

Now, let's come back to the old Egyptians. We learned something from the queen's necklaces. Perhaps we can learn something more from these examples:





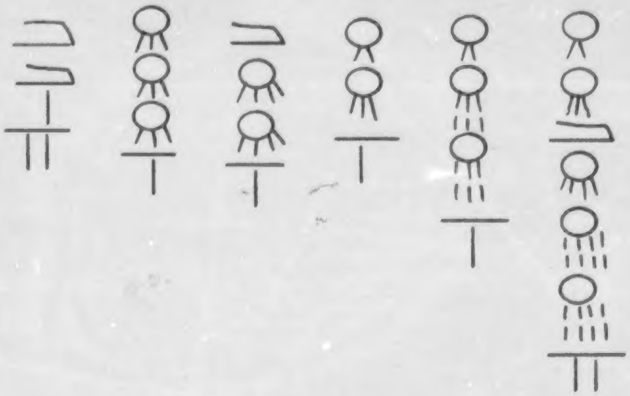




Bas-relief from one of the stelae of Aahmes, at Turah, Eighteenth Dynasty

We already knew the values for |, ∩, and 𓍢. What does 𓆼 stand for? Clearly, another thing about the old Egyptians is that they wrote from right to left ←, whereas we write from left to right →.

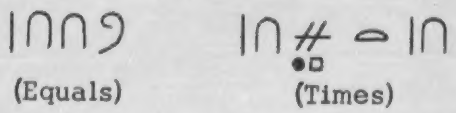
Here are further examples of Egyptian numerals. Can you find values for these?



Vignette from the Book of the Dead, Saite period

This is the way the Egyptians stated a problem in multiplication:

Step 1

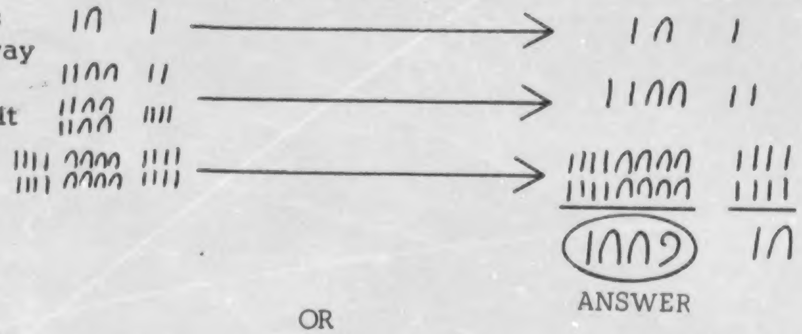


(We would say 11 x 11 = 121)

Step 2

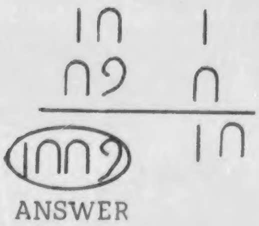
Step 3

And this is the way they worked it out



OR

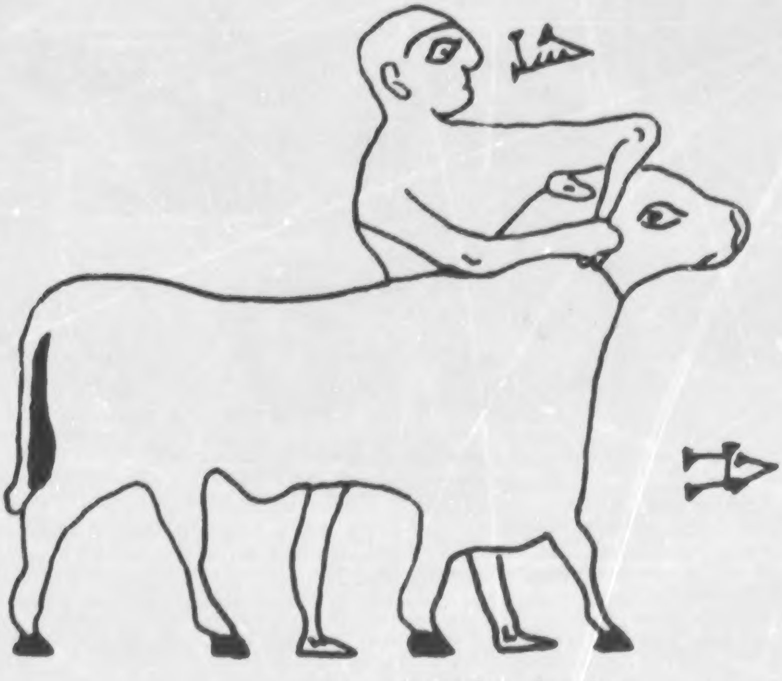
Alternative step 2



Do you see what they did? They took 11 once |∩ , then 11 twice, and so on. They watched the right hand column, and when they had a set of numbers that added up to 11, they took these along with the corresponding numbers in the left hand column and set up a new double column (Step 3). Adding up the numbers in the right hand column, you get

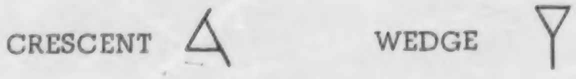
11, while the sum of the numbers in the right hand column is 121, and that is the answer to the problem. Also, in this case of 11 x 11, you could take 11 once, and 11 ten times. This would give 11 in the right hand column and 121 in the left as shown on the previous page.

More than five thousand years ago, shortly before the Egyptians began to make records like the tags that were attached to the queen's necklaces, another ancient people had begun to use a different system of writing. This was called the cuneiform (wedge-shaped), and it was invented by a group of people called the Sumerians who lived in Mesopotamia (Iraq). The signs or characters for writing the cunei-

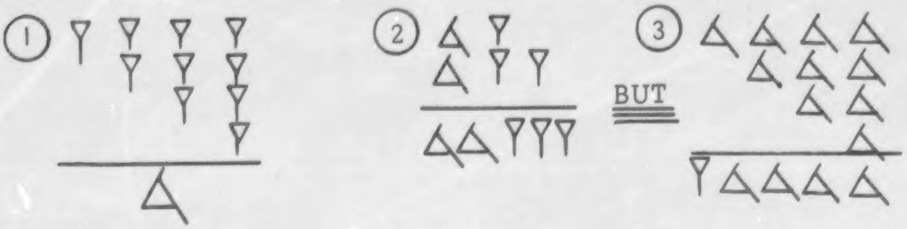


Sumerian drawing

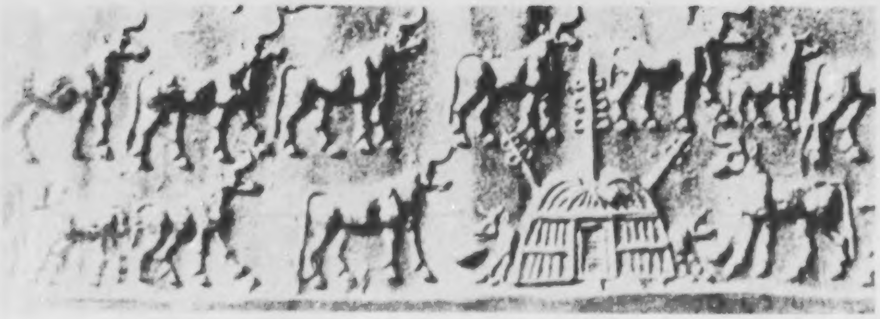
form were made by pushing the edge of a square-ended stylus or writing tool into the surface of a damp clay tablet, or block of clay. By merely using the end of the stylus, a crescent could be made; if the edge of the tool was then pressed into the clay, a wedge resulted. All cuneiform characters consisted of crescents or wedges, or combinations of both crescents and wedges.



Here are examples of addition. Can you determine the values of the wedge and the crescent?

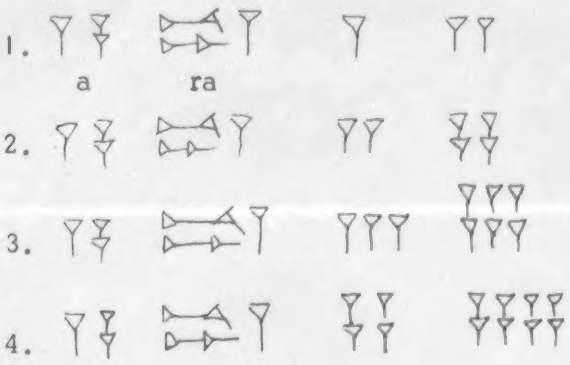


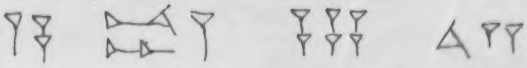
Sumerian drawing

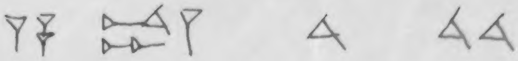


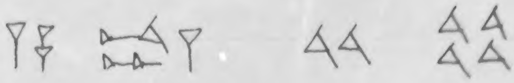
Impression from a cylinder seal from Khafajah of the Jemdet Nasr period

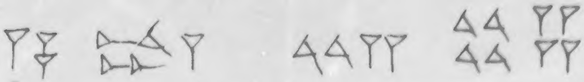
First, it should be said that the Sumerians wrote from left to right, the opposite direction from that used by the Egyptians. Second, while examples 1 and 2 are clear enough, what do you think about example 3? What must be the value of the wedge in example 3? Perhaps an example of another sort will be helpful. Here is a table used by Sumerian schoolboys. The first two characters which appear at the left in every line are to be read a-ra. The characters in the next two columns are numbers. Perhaps you can figure out how to translate a-ra after you have studied the numbers in lines 1-8. After that, study lines 9-14 and see if you can distinguish the two ways in which the wedge is being used.

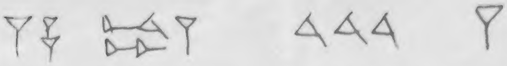


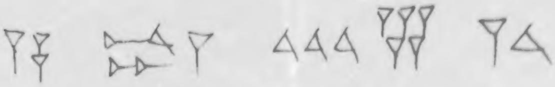
5. 

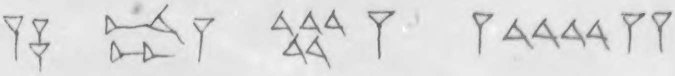
6. 

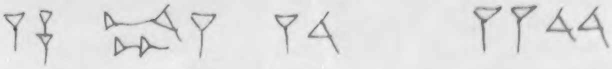
7. 

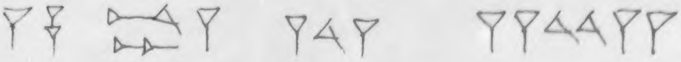
8. 

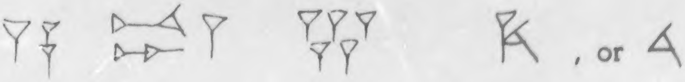
9. 

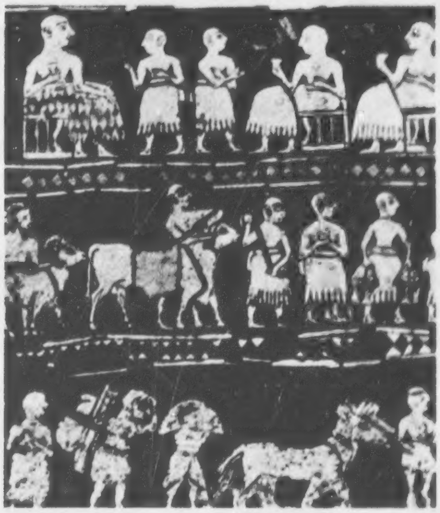
10. 

11. 

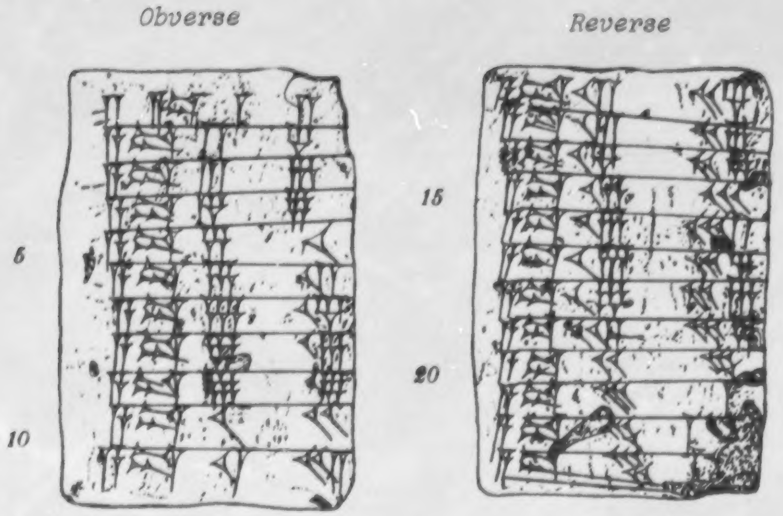
12. 

13. 

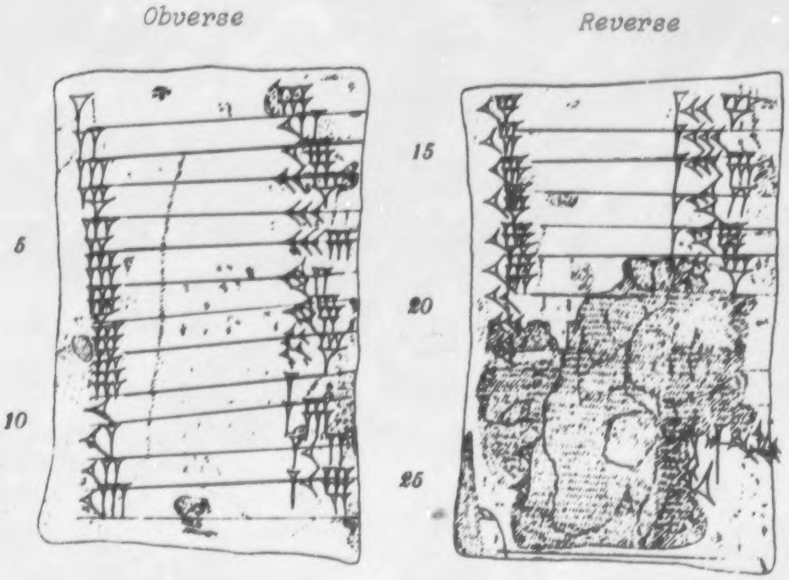
14. 



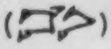
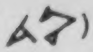
Sumerians at work

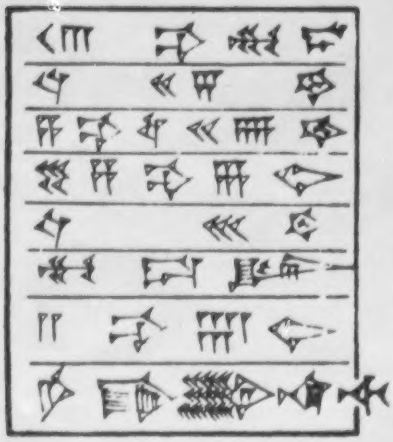

Obverse
Reverse
5
10
15
20

The first line of this clay tablet reads "2 X 1 = 2"


Obverse
Reverse
5
10
15
20
25

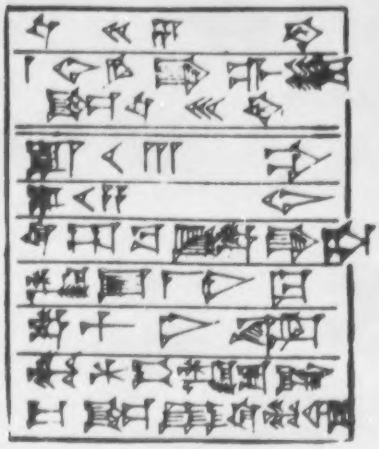
What is this table?

Below is a record of oxen () and cows (). Can you read the numbers of the animals and the day of the month on which they were paid out?



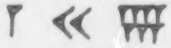
______ oxen, brought in
on the 25th day
______ oxen, on ______ day
______ oxen ______ cows
on ______ day
Royal delivery
______ oxen ______ cows

gift



on ______ day
______ cows, gift
on ______ day
total ______ oxen
total ______ cows
from X
Y took in charge
Month name

Year name



Grand total of oxen and cows

Now, this cuneiform system for the numbers differs from the other systems we have looked at. First of all, it is a "place system." In this respect, it is like the Hindu-Arabic system. For example, 125 in the Hindu-Arabic system really says 100+20+5, or 2564 really says 2000+500+60+4. In like manner 𒁹𒌋𒁹 says 60+10+1. Thus, 135 in the cuneiform would be written 𒁹𒁹𒌋𒐊, or 60+60+10+5.

On the other hand, the Hindu-Arabic system is a decimal system, based on 10, while the cuneiform uses a sexagesimal system in which 60 rather than 10 is the basic number.

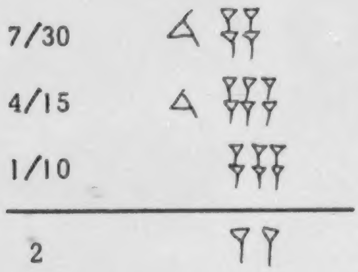
In a sexagesimal system the fractions take new and interesting forms. When a Sumerian said "igi 2 gal" he meant ½, but he wrote 𒌋𒌋𒌋 because ½ of 60 is 30. "Igi 4 gal," ¼, would be written as 15 (𒌋𒐊).

Can you write in cuneiform the following:

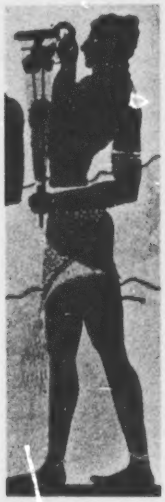
1/3, 1/10, 2/3, 1/6, 1/4 ?

At any rate, it is easier to add fractions in the cuneiform than in our system. Can you add quickly 1/3, 2/5, 5/12, 1/4, 7/30, 4/15, and 1/10? In cuneiform, this would be:

1/3	𒌋𒌋
2/5	𒌋𒌋 𒐉
5/12	𒌋𒌋 𒐊
1/4	𒌋 𒐊

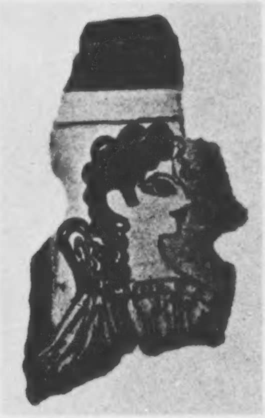


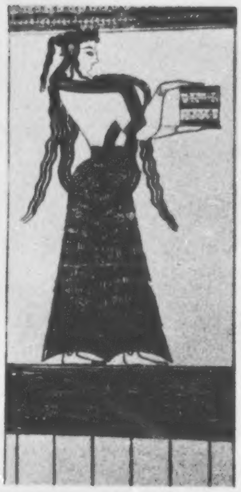
About 3500 years ago a strange people lived on the island of Crete in the Mediterranean Sea. We call them the Minoans, but we do not know what they called themselves. Minoan kings lived in great palaces consisting of scores of rooms decorated with bright, handsome wall paintings. The people themselves were mostly farmers and herdsmen, but there were also skilled artisans who made beautiful painted pottery, ivory carvings, and many objects of gold and silver. Above all, the Minoans were traders who voyaged to Greece, Syria, Palestine, and Egypt. Like the Sumerians and the Egyptians, the Minoans kept records of their possessions.



Fresco of cupbearer from Cnossus.

Fresco of girl from Cnossus

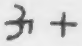




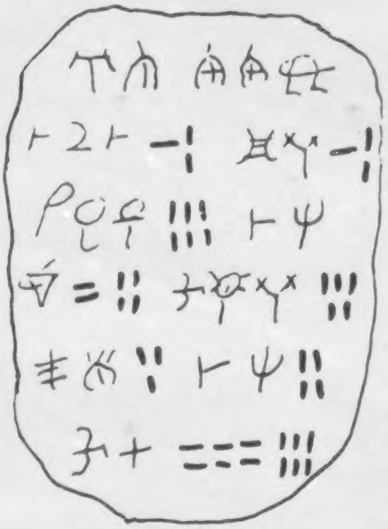
Minoan woman

They had their own system of writing, and they scratched their accounts on flat tablets of clay. Since we do not know what language the Minoans spoke, we cannot read their records except for the numerals.

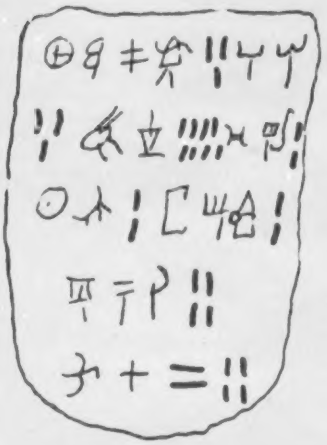
Look at examples A and B on the next page. These record amounts of commodities or numbers of things provided for a temple by individuals or communities.

1. See if you can find the characters for the numerals.
2. Can you decide what  means?

Minoan gemstone

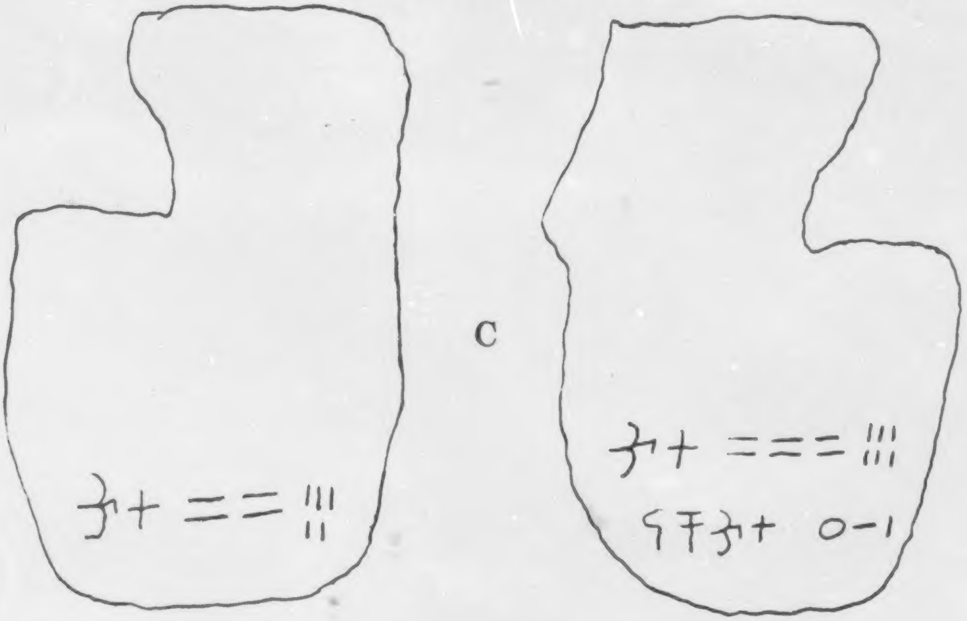


A



B

C



SIDE A

SIDE B

3. What do you think the different numerals stand for?

Example C shows two sides of the same tablet. Side A is the front and Side B, the back. Only the totals on each side are shown.

1. Can you decide what ᑫ T̄ Ʒɿ+ means?

2. Do you think the Minoans used a decimal system? Why?

While the Minoans flourished in Crete, the first Greeks arrived in Greece. They began to trade with the Minoans, and they borrowed many elements of Minoan civilization including the Minoan system of writing.

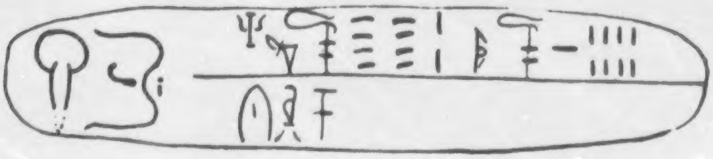
The Greeks of this period whom the archaeologists call the Mycenaeans were ruled by kings who lived in great walled palaces situated on hilltops. In the palaces were rooms of state, living quarters, shops for making pottery, metal work, weapons, and storage rooms. The Mycenaeans used their system of writing, a modified form of the Minoan script, to keep records of their possessions and the taxes paid by the people to the kings.

Below you will see drawings of the inscribed clay tablets on which the Mycenaeans kept track of their sheep, cattle, horses, grain, and so on.

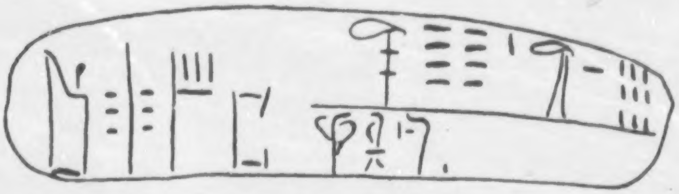
In Section A can you tell which symbols stand for the numerals? Do you think a decimal system was used?

Section A

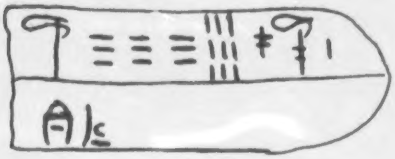
①



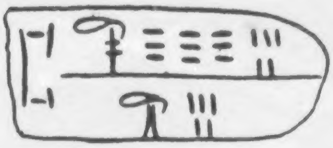
②



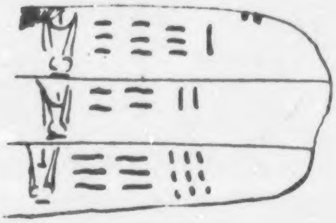
③



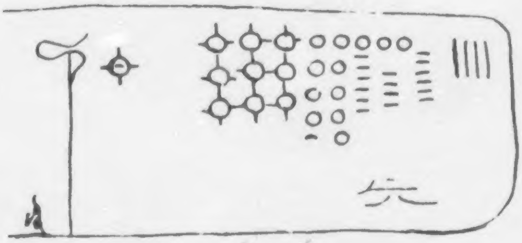
④

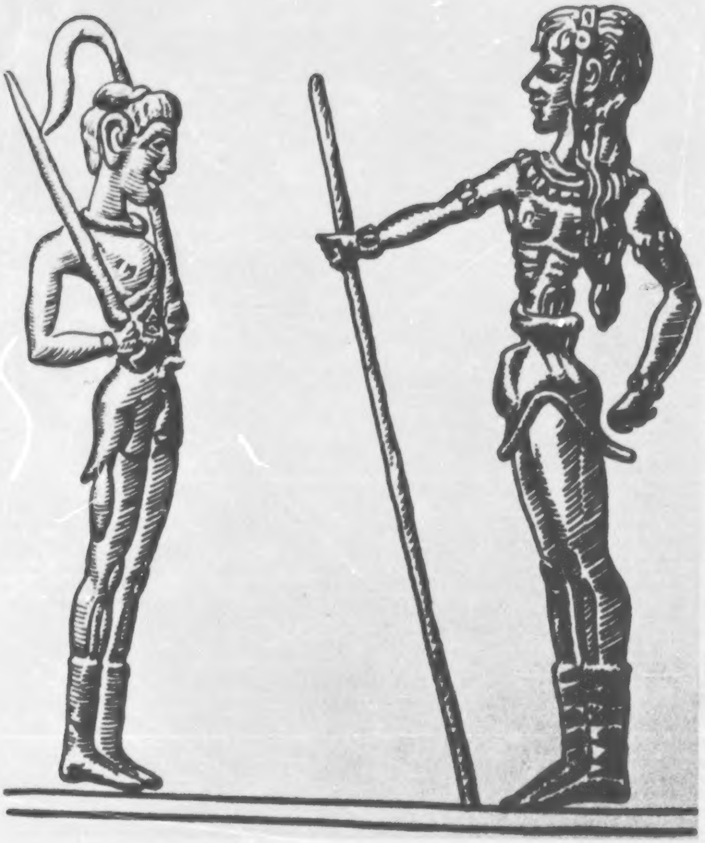


⑤



⑥





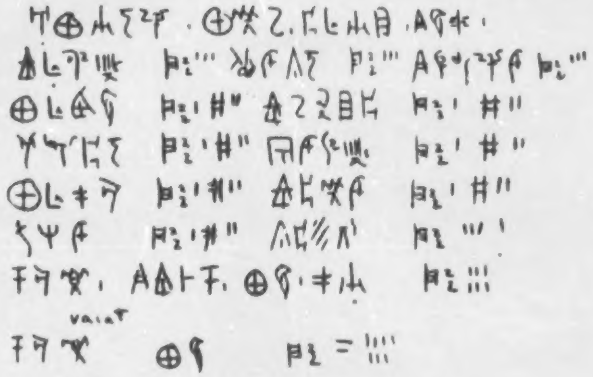
The Prince and the Warrior: Chieftain Vase, (Minoan)

What do you think / , — , O , 𐄢 and 𐄫 stand for?

Why do you never find more than 𐄏 or 𐄘, and so on?

In Section B you will see tablets that record the names of people and the amounts of their contributions to the king. Can you find the word for "total?"

①



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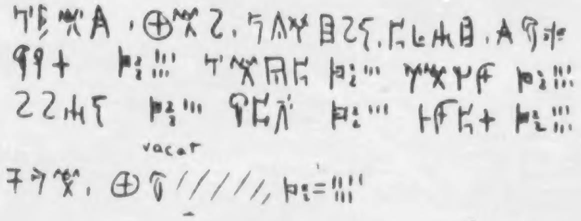
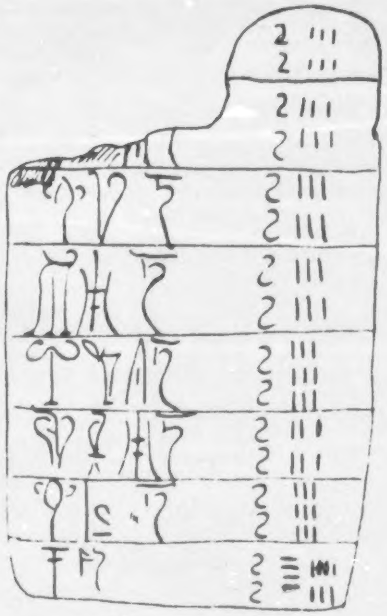


③



These are only a few of the kinds of numerical notation used by the people of long ago. We have said nothing about the ancient Maya who lived in Middle America and used a vigesimal system in which 20 was the basic number. Neither have we mentioned the Chinese and Japanese whose preference was for a decimal system. Beyond this, it is interesting to study the various ways in which the ancients tried to simplify and streamline the solution of problems in multiplication, division, and calculations involving fractions. From what you have already seen, you should not be surprised to learn that some of their methods were very ingenious and in some ways better than the ones we ordinarily use today.

Procession on warrior-vase: Mycenean

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